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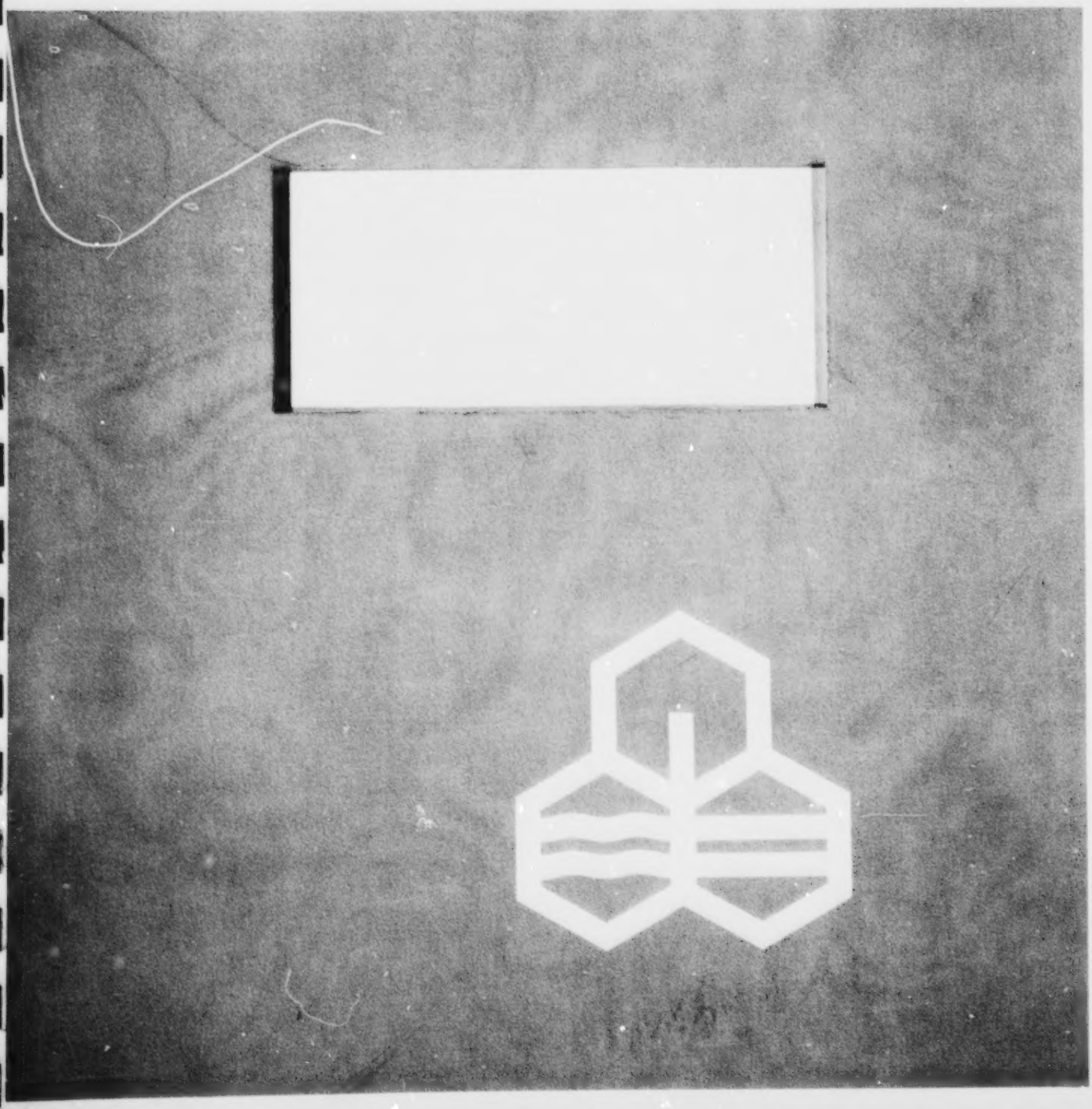

ECOLOGICAL INDICATORS

OF THE STATE OF THE ENVIRONMENT:

Report of a Workshop held May 27-29, 1987

at the
Institute for Environmental Studies
University of Toronto

Edited by Pamela Stokes and Darrell Piekarz

for
Environmental Interpretation Division
Environment Canada

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EXECUTIVE SUMMARY

Preamble

In order to assist Environment Canada in state of the environment (SOE) reporting, a workshop was convened by the Institute for Environmental Studies in May 1987. Participants included members of the core group working on SOE in DOE and Statistics Canada, individuals from a variety of federal programs and a number of academics. The speakers and the working groups addressed selection criteria for indicators at different levels of ecosystem organization, and identified the important variables that should be measured for the sustainable management of renewable natural resources. Following the workshop, case studies on different types of indicators, as well as on novel monitoring programs, were commissioned. The case studies are intended to complement the workshop and the authors chose their own topics. These are included in Chapter 10 of this report.

The following items summarize the main themes introduced by the speakers (name in brackets) and the conclusions reached by the six working groups.

1. There is a requirement for baseline data if we are to evaluate environmental change. Baselines covering a number of human generations have been suggested to encompass occasional natural events that affect systems and influence measurements. The dynamics of the system that we choose to study will suggest the appropriate time frame. In the absence of historical data, inter-regional comparisons using data gathered from ecological reserves or national parks may be used. (Bernard)

2. Variables selected from monitoring programs must reflect the state of the environment. They should be understandable to non-specialists including policy makers while being scientifically defensible. It is necessary to define the kind of change (or problem) that one wishes to describe and then develop suitable indicators.

3. In their application, one must keep in mind that indicators as summary variables have the highest utility in relatively homogeneous landscapes. Indicators of land use provide good general information of change over time; data or derived information are usually available. Indicators of ecosystem change may prove to have more diagnostic value (where measurements are available). Hypothetically, ecosystems under stress exhibit some or all of a common group of symptoms or an "ecosystem distress syndrome". (Rapport)

4. In deciding on "what question an indicator species answers", the criteria for sampling must be known, as well as the applicability of the indicator to scale or level of ecosystem organization. At all scales, indicators may be predictive or descriptive, show trends, and provide a measure of response. At the macroscopic level, our interest in trends is also geographic while at the microscopic level we need to examine metabolic change.

5. Although indices (computed values) appear to integrate information, they are of often limited use in giving insight into the variability of the system or factors influencing its behaviour over time. Indices may be quite non-specific and inherently their use results in the loss of information. (Stokes, Bernard)

6. In the assessment of cumulative effects, the focus is on the carrying or assimilative capacity of ecosystems. Robust indicators in this context provide early warning signals of impending structural or functional change or 'surprises'. The Adaptive Environmental Assessment and Management approach (AEAM) through the selection and monitoring of key processes and populations can quantify the degree of restoration achieved. Indicators are thus useful in designing programs to help reverse the undesirable effects of human activities. (Bernard)

7. Water quality objectives provide little assurance that aquatic biota are protected from the effects of chemical exposure. Biochemical monitoring of the responses of individual organisms provides the manager with the most sensitive and earliest indicators of exposure and effect. To wait for responses to appear in populations, communities or ecosystems, species or resources may be put at risk. (Hodson)

8. Calibration of the relevant biochemical responses to the population level and higher will provide an important diagnostic tool in the future. As biochemical techniques become more widely accepted, the need for expensive and time-consuming ecosystem studies will be reduced. (Hodson)

9. Chemical indicators have a recognized role in recording the present status and predicting the future state of the environment. In both terrestrial and aquatic ecosystems, nutrient loss (leakage) can be used as an early warning indicator provided good baseline data are available. On the other hand, accumulation of chemicals is related to possible dysfunction of ecosystems (e.g. CO_2 build-up, eutrophication). Interface measurements (e.g. air/soil, air/foliage) may help to explain the processes involved.

10. Indicators of soil quality are well known. There is consensus that measures of organic matter, wind and water erosion, acidification, salinity and bulk density tell the story. Organic matter is strongly correlated with the degree of aggregation of the soil which strongly influences biological production and controls soil erosion. Deterioration of soil resources is well known on a site specific basis. Nationally, consistent field samplings and laboratory analysis are lacking. Documentation on soil variability and physical properties is inadequate. This weak information base limits our ability to assess old and new soil management techniques in agriculture and forestry. (Pennock)

11. "Balanced information services" are required for the management of renewable resources. The interaction of the natural and cultural systems will yield information particularly useful to management. Taking scientific research as a valid paradigm for understanding the living world, information is provided through mapping, monitoring and modelling. Insight and information enter the management process through interpretation and assessment. Although this packaged information appears in the form of indicators or indices, it is not simplistic*. A balanced information service must also contain an evaluation function. Periodic self-evaluations by organizations and

* see page 149 for criteria used for evaluating indicators of marine and Great Lakes environmental quality

agencies should address the general relevance and cost effectiveness of research (monitoring, mapping and modeliing). By closing the loop, innovative and relevant information may be produced. (Regier)

12. In order to achieve the sustainable management of fisheries resources, there are variables and thresholds which are useful. Detailed field collection of biological data should be emphasized. Early warning indicators of changes to population include habitat loss, reproductive failures, sub-lethal morphological/ histopathological changes, the bioaccumulation of a variety of substances, diversity shifts and bioassay testing.

13. Most changes in forest ecosystems are initiated by episodic events associated with human activity or are naturally caused. Recovery depends on a variety of physical factors and the nature of the disturbances including their frequency. To separate man-made change from natural, monitoring networks are needed with stations covering different pollution levels and forest types. In this connection, long-term data sets are needed. Changes in nutrient dynamics of the soil, growth of key tree species and wildlife diversity will help to complete the evaluation. (Kimmins)

14. Although baseline data are generally lacking, calibrated models can be used to simulate a baseline against which the monitoring of structure and functional change can be compared. Monitoring data of undisturbed forests can validate such models. (Kimmins)

15. Models are a valuable tool in exploring the consequences of various forest management strategies on a site-specific basis. They should be able to predict soil organic matter, vegetation biomass, growth rates and wildlife habitat, as well as predict the effects of chronic stresses such as air pollution, acid rain and global warming.

16. The forest industry is a "tenant farmer" of an existing crop. Until recently, little concern has been expressed by these companies in

long-term management of forests. Protection of species and preventing their loss should be a goal of management. This would involve the preservation of sufficient habitat. On the other hand, cutting trees in protected areas may be fully justified in terms of "ecological preservation". (Kimmins)

17. Sustainability with respect to agriculture covers a number of factors and any assessment must incorporate a similar range of indicators. The maintenance of the physical base (soil), economic and social viability, and the intrinsic strength of the production system are the most important factors. There is a critical need to document cropping systems and establish their relationship to physical, chemical, biological and economic conditions. (Huffman)

18. New monitoring of agriculture land is necessary and should include county level surveys of trends in soil organic matter, nutrient content and erosion. Cropping practises could be surveyed through the use of remote sensing technology and existing census of agriculture data.

1. INTRODUCTION AND RATIONALE

State of the environment (SOE) reporting is a process that attempts to bring scientists, decision-makers and the public to a common understanding of environmental conditions and trends. In 1981, Environment Canada and Statistics Canada undertook the preparation of a prototype report and in 1986 The State of the Environment Report for Canada was published. Formal arrangements have since been made to continue this type of work in the federal government. A national report will be published in 1991 and an electronic system for public access to environmental data (and analysis) is to be implemented. A central feature of environmental reporting is the presentation of summaries of data on environmental change over space and time. Ideally we would also like to be able to inform the reader or data user of the significance of observed changes.

Characteristically, SOE reports rely on data from monitoring programs that have been set up to obtain specific information: eg. harvesting levels, compliance with regulations or chemical impacts on organisms subject to direct human consumption or use. The stress-response statistical framework, used by Canada and the Organization of Economic Cooperation and Development (OECD) brings coherence to the existing data and also serves as a means of identifying missing information. The Canadian SOE report and statistical compendium present five distinct categories of environmental stress: harvesting, contaminant loading, physical restructuring, exotic introductions and natural events.

In addition to direct measurements of these stresses, enumerations of socio-economic activities known to perturb ecosystems have been recast into environmentally relevant units (terrestrial ecozones). These statistics are useful surrogates for information on monitoring and surveillance information; they may also point out habitats where responses ought to be measured. Mapping the forms of environmental restructuring gives an indication of the conversion of natural systems to managed ones or to degraded ones. Trends of these kinds

of information have been used to alert decision-makers to environmental change.

Although there continues to be methodological difficulties associated with the aggregation of micro-scale data for the purposes of macro-scale state of environment reporting, a degree of success has been achieved in describing environmental stress created by human cultural activities.

Environmental response to stress is relatively clear in instances where causality can be precisely defined, for example in land-use change. Data recording such phenomena are plentiful. There is also some consensus as to the characteristics reflecting ecosystem response to stress. Changes in productivity and species diversity, increased disease incidence, changes in the population and individuals of the dominant species, and reversion to an earlier stage of community development have each been used with varying degrees of success at the systems level. Absence or limited nature of data have often precluded a thorough analysis of the appearance of these symptoms and their significance.

The identification of ecological indicators and the collection of the requisite monitoring data would ideally serve to diagnose the "health" of ecosystems, anticipate change, assess the extent of perturbation, and signal the recovery of ecosystems. The utility of indicators is of course greatest if the relationship between stress and response is understood. Indicators also need to be selected to depict the functional changes at the individual, population, community and ecosystem level. Some criteria of scientific defensibility need to be applied. With the possible exception of the Great Lakes ecosystem, State of the Environment reports have had limited success in providing information on the significance of ecological change, the extent to which critical thresholds have been crossed, and the nature of the managerial intervention to be recommended. Until this is accomplished, there is little prospect for environmental reporting to become useful to government and corporate decision-makers.

In a specific attempt to develop biological and chemical indicators useful for SOE reporting, Environment Canada sponsored a workshop which was organized by the Institute for Environmental Studies at the University of Toronto. Speakers were chosen to address 1) Selection criteria for indicators of 'natural' systems, 2) indicators of sustainability in managed systems. Working groups were formed to discuss these topics and to recommend the kinds of new monitoring programs that would be required. This report summarizes the workshop proceedings.

A note to the reader. You will find great variability in the range and manner of coverage of topics covered by the speakers and discussions. We have not "forced" discussions into any standard format. We hope you will find them stimulating and thought-provoking.

A series of short papers or case studies which have specific relevence to some aspect of ecological indicators or environmental monitoring, have been included (chapter 10). These were contributed by some attendees of the workshop, in response to a general request by the organizers, but were in the nature of voluntary submissions. No attempt was made to have case studies cover all the concepts that were introduced, nor all the areas of concern. Case studies were submitted after the workshop, so they may reflect the discussions, but were not themselves discussed at the workshop.

ACKNOWLEDGEMENTS

The editors would like to thank the invited speakers who set the tone of the plenary sessions and who led discussions in the work groups. We also thank the rapporteurs for volunteering their journalistic skills and for organizing their material so well. We also appreciate the work done by Desiree Toom and by Chris Radewych in organization and administrative support. Finally, we would like to thank Chris Radewych for typing the final report.

2. CRITERIA FOR ECOLOGICAL INDICATORS

2.1 Introduction, David Rapport.

It appears to be a spring ritual to convene seminars on this topic. Over the past decade, efforts have been made to come to grips with the question of environmental indicators and environmental monitoring systems. In considering these questions anew, one should not lose sight of the good efforts already made in major workshops on the topic, including the International Joint Commission (Toward a Transboundary Monitoring Network: A Continuing Binational Exploration Vols 1 and 2, June, 1986); the various workshops of The Institute of Ecology (TIE) on the subject of Ecosystem Health, the workshop of the Great Lakes Fisheries Commission, compiled in the volume on Contaminant Effects on Fisheries (eds Cairns and Hodson, 1984, Wiley and Sons); the work of International committees on environmental monitoring and indicators (eg. European Economic Commissiion (Geneva), Organization for Ecomonic Cooperation and Development (Paris), Helsinki Commission (Helsinki), International Commission for Exploration of the Seas (Copenhagen) and other bodies, far too numerous to name here.

While a review of these and other initiatives in the area of environmental indicators may prove laborious, it is a necessary task and proper starting point in the development of new approaches to the indicator question.

With regard to the question of criteria, I here recall the three "R's" of all well-chosen evironmental indicators: The first is Relevence -- by that I mean relevence to whatever notions of ecosystem health are accepted and agreed upon as a socially desirable criteria (eg. productivity, quality of biotic community, diversity, etc.). The second is Reliability. The problem with many potentially fine indicators is that they are simply unreliable given our current state of technical capability. The efforts to measure primary productivity in the open sea, and the recent discovery that the available estimates may be "off"

by an order of magnitude or so, furnishes an example. The third criterion is Robustness. Ecosystems are under stress from a variety of forces, some from human actions, others from extreme, but "natural" events. For general environmental assessments, indicators ought to be responsive to a wide variety of pressures, rather than being honed to a few circumstances.

Of course other criteria are also relevant in developing a balanced set of indicators. One consideration is the degree of specificity. Some indicators are highly stress specific. Often these are found at the lower levels of biological organization (eg. abnormalities in physiology, behaviour) while others are of a more general character. Generally these are found at the upper-end of the spectrum of biological organization, (eg. changes in efficiency of energy flows or nutrient recycling). Another dimension is provided by the Retrospective-Prospective axis. That is, the various indicators might be judged to be "early" or "late" in appearance with respect to ecosystem damage. These considerations are illustrated in Figure 2.1.

The question of whether or not ecosystems "feel" pain is not as interesting as the question of whether or not ecosystems become disorganized by stress. The hypothesis proposed by Rapport, et al, (1985) is that ecosystems under stress exhibit some or all of a common group of symptoms, giving rise to the notion of an "ecosystem distress syndrome". The syndrome has provided much in the way of guidance for the choice of environmental indicators, and indeed formed the conceptual basis for the selection of aquatic indicators for the prototype State of Environment Report for Canada.

Indicators of Ecosystem Degradation in the Great Lakes
Change in Community Structure and Function
Decreasing Size in Fishes
Disappearance of Sensitive Species and Families
Behavioral and Cellular Abnormalities (Organism level)
Structural and Behavioral Properties (Ecosystem level)
Histological Abnormalities in Fish
Reproductive Failure in Herring Gulls
least
Relative Diagnostic Potential
MOST
MOST
Relative Early Warning Potential
least

Figure 2.1

Figure 2.1. Indicators of ecosystem degradation in the Great Lakes. Early warning indicators signal the onset of the process of ecosystem transformation under stress. Characteristically, these symptoms appear at subecosystem levels such as changes in physiology and behavior of sensitive species. An example might be liver histopathology in benthic fish, or abandonment of preferred spawning or feeding habitat by nearshore fauna. Retrospective (historical) indicators confirm widespread ecosystem transformation. These include changes in nutrient concentrations of waters, changes in community structure (e.g., in the Laurentian Lower Great Lakes pelagic fishes have generally displaced the benthics). In some cases, symptoms are diagnostic of a particular type of stress (e.g., contaminant accumulation in Herring gull eggs). More generally, however, the symptoms of ecosystem distress are nonspecific as to causal agent. Examples in figure are from the Laurentian Lower Great Lakes.

Source: Rapport, 1984.

One of the great obstacles to evaluating environmental change is the lack of "base-line" data. The "base-line" can be variously defined— eg. the historical state of the system, the projected evolutionary state of the system, the socially desirable state of the system, etc. Whatever the specification of "base-line" conditions, there ought to be the notion of sustainability, or persistence of an integrated ecosystem which yields the diversity and quality of structures and processes deemed healthy. This then would provide the basis for judgements as to the current state of affairs.

How might environmental prognosis be introduced into State of Environment Reports? This is an area which needs research. Obviously, for all their virtues, State of Environment Reports are at best historical documents, recording what has happened,but offering little in the way of what might happen--i.e. what is around the corner. Here enters a notion of risk assessment, which if correctly developed for environmental data purposes might yield "leading indicators" of considerable interest to decision makers.

2.2 Question to D. Rapport (from Doug Evans)

Q. Can you provide us with a rigorous definition of the term "stress", since it seems a bit circular to define indicators of stress in the absence of the definition of stress?

R. See Rapport, Regier and Hutchinson, (1985), for our definition of stress. This definition has been adopted for purposes of cross disciplinary discussions at the forthcoming Linnean Society Symposium on Evolution, Ecology and Environmental stress. "Stress" is used to denote an external force of factor or stimulus that caused changes in an ecosystem, or causes it to respond or entrains ecosystemic dysfunctions that may exhibit symptoms. "Response" is used for an internal effect of a stress on a system. Perturbation, dysfunction, distress syndrome are approximate equivalents.

I separate "stress", which is the externally applied force on an ecosystem from "response" which is the result of the pressure. Thus loading of phosphorus to a lake is a "stress", and algal blooms, a response.

References

1. Rapport, D.J., H.A. Regier and T.C. Hutchinson, 1985. Ecosystem behaviour under stress. American Naturalist, 125:617-640.

2. Rapport, D.J., 1984. State of Ecosystem Medicine, pp. 315-324, in Contaminant Effects on Fisheries, eds. V.M. Cairns, PV. Hodson and J.O. Nriagu. John Wiley & Sons, Inc. (Figure 1, page 318).

3. INDICATORS AT THE BIOCHEMICAL AND SPECIES LEVEL

3.1 Biochemical Monitoring of Chemical Effects on Fish, Peter Hodson.

Chemical monitoring of aquatic ecosystems provides a description of the potential chemical exposures of aquatic biota and a measure of the success of pollution control. However, meeting water quality objectives provides no assurance that aquatic biota are protected form the effects of unexpected chemicals, mixtures and the interactions between chemical exposure and environmental stress.

Biological monitoring appears to be an obvious solution to this problem, since aquatic biota will integrate spatial and temporal variations in exposure and the effects of all combined stresses. Unfortunately, environmental and fisheries managers cannot rely on populations, communities or ecosystems to indicate chemical effects. The time lag between identifying a problem and finding a cause may allow a complete destruction of the resource that we wish to protect, particularly where chemicals are persistent.

A solution to this dilemma is biochemical monitoring, the measurement of primary or secondary responses of individual organisms to chemical exposure. Since all toxicity at any level of organization must start with a reaction between a chemical and a biological substrate in individual organisms, these responses will provide the most sensitive and earliest indicators of chemical exposure and effect.

Application of this idea requires additional research on the molecular mechanisms of chemical toxicity in aquatic organisms and intelligent adaption of existing mammalian diagnostic tools. Since relevance of biochemical responses to populations and ecosystems is not always obvious, there is an even greater need for landmark studies that link chemical exposure to responses of individuals, populations and ecosystems. Such 'calibrations' will reduce the

need for expensive and time-consuming studies of ecosystems and will increase the acceptability of biochemical techniques.

3.2 Question to Peter Hodson (from Magda Havas)

Q. There was one sharp contrast between what you said and what David Rapport said about the relevance of the early warning indicator. You stated that it should have a "specific relevance" while Dave said it should be "relatively unimportant". Would either of you care to comment?

R. Relevance can be discussed on several levels. An early warning indicator should have relevance to some specific stress (ie. a response points to a diagnosis) and to some subsequent change at a higher level of organization (eg. warning of reproductive failure). By itself however, it should have little direct relevance - a response should not involve ecological change but rather a change in some physiological response (eg. hematocrit) that is trivial in ecological terms.

3.3 Rapporteur's report of Work Group A.1, Indicators at the Species and Biochemical Level, Kristin Day

We started with two main objectives:

1. To develop criteria for indicators (generic).
2. To propose a list of species level indicators.

We distinguished predictive from descriptive factors including effect from cause, effect from effect and cause from effect. We also distinguished between specific indicators and integrators. We also looked at the nature of stress, the importance of species, environments - managed or unmanaged, and locations.

The group felt that we answered objective #1 but did not get very far with objective #2 - The list of "key" species.

The group immediately had problems with terminology and we started a glossary of terms. The main discussion centered around the use of the phrase

"health of ecosystems". All ecosystems have the "ability to self-regulate" but, health or the word quality implies a value judgment. Therefore we should be looking at indicators of change, not of "health" or "quality".

We then went on to discuss the notion that one needs to know the end product upon which the decision is to be based. Therefore it becomes necessary to decide what question we want to answer with our indicators before we can decide on key species lists. The group concluded generally that we cannot rely on one sampling program for all stresses. The criteria for sampling must correspond to the question that is being asked and be defined according to scale or level of organization (eg. macroscopic vs microscopic).

Characteristics of Response Indicators

Macroscopic (ie. population, communities)	Microscopic (ie. enzymatic, cellular)
slow	fast
insensitive	sensitive
non-specific	good diagnostic potential

The group spent approximately half of its time discussing Henry Regier's (Appendix D) list of criteria for indicators. The relevant points of the discussion were as follows:

1. Is national coverage of importance?

Yes/No - a type of measurement can be compared across Canada i.e., a chosen indicator should represent the same niche in the ecosystem but obviously the actual species may differ. A problem occurs with species that can migrate/emigrate/immigrate because they may be stressed in one region but be sampled in another. Therefore we need to choose species with a restricted range in an ecozone.

2. Pollution-related.

This criterion actually relates to the question of geographic distribution; again, it means that the indicator must be stressed where it is sampled.

3. Scientifically defensible.

The group felt that a two-day workshop would be necessary for a good discussion of this point. In fact, this point relates to the issue of key indicator species.

4. Baseline data.

Yes/No - the group questioned what "adequate" means? The point was made that this prerequisite might eliminate new ideas/new techniques, if such techniques were not previously available and therefore had no history.

In general, the group agreed that it is good to collect baseline data and that we especially need archival collections of tissues and sediment (banks) so that we can relate the development of new techniques to older samples. Geographical data collection was also considered to be important.

5. Reliability.

The group agreed that quality control QA/QC must be in place. Sampling design must also be adequate.

6. Simplicity.

The group decided that simplicity was not the proper term. It should be <u>feasibility</u> which takes into account such factors as cost, equipment, expertise. We should also be able to express our results simply to the public or to regulators.

7. Quantitative.

Yes, but some qualitative data such as behavioral changes should not be discarded.

8. Additional Criterion.

The group felt that number 1 on Henry Regier's list (Appendix D) should be definition of the problem, before indicators are chosen.

3.4 Question/Comment to Kristin Day (from Hamish Kimmins)

Q. Re: Criterion of Simplicity. Efficiency should be combined with simplicity as a monitoring criterion.

Research in ecology and various areas of resource science has often suffered from what is called "Occam's razor", which says that simple theories and hypotheses are better than complex ones because they are more readily tested and are more refutable. Adherence to this principle has led ecologists to seek and test reductionist, causal hypotheses about complex, ecosystem-level landscape phenomena. Such theories and hypotheses have often been naive and ineffective. Theories, hypotheses, and monitoring criteria should be as simple as possible, commensurate with being efficacious. But a simple hypothesis that does not adequately describe the phenomenon is of little value. Hypotheses should be sufficiently complex to "do the job".

R. Agreed. We discussed this without putting a term to it.

4. COMMUNITY OR ECOSYSTEM LEVEL INDICATORS

4.1 Introduction to Indicators at the Community or Ecosystem Level, David Bernard

This presentation was designed to serve two purposes:

1. to summarize practical experience in selecting indicators at the community or ecosystem level for use in environmental monitoring programs, and

2. to provide questions that would serve as focal points for working group discussions.

Accordingly, the introduction is built around the following three questions:

1. Is there anything that can be measured at the ecosystem level that cannot be measured at the community (or lower) levels?

2. What types of indicators are appropriate for use in monitoring programs designed to detect problems involving cumulative effects?

3. What role will monitoring of indicators play in helping us determine whether efforts to restore damaged ecosystems have been successful?

During the presentation, attempts were made to highlight issues associated with these questions, rather than answer them.

Indicators are used in monitoring programs to simplify the task of measuring environmental change. Conceptually, this is a simple and appealing idea, but difficulties typically arise when choosing what to measure, how to do so, and when. Indices (computed values) can be created to integrate the state of the environment, but interpreting the results may be difficult. For example, few indices provide estimates of variability or give insights into factors that influence the behavior of the system. Thus, indices are somewhat analogous to looking at GNP values for a national economy. Although they provide a 'snapshot' of the system, they are usually of little use in gaining an understanding of either why the system is behaving as it is, or in determining what will happen next.

In this presentation, the Adaptive Environmental Assessment and Management (AEAM) approach to selecting environmental components for measurement and

monitoring was outlined. AEAM emphasizes deliberate selection of key processes and populations for measurement, based upon the specific goals of the monitoring program. AEAM is one of the few existing procedures for assisting individuals faced with selecting indicators that will be used in a monitoring program. Our experience with selecting indicators suggests that usually it is impractical to try monitoring directly at the "ecosystem level" for effects. Hence, the focus on processes and populations.

In the past few years, there has been considerable interest in methods to assess cumulative effects. Cumulative effects assessments differ, in part, from traditional environmental effects assessments by focusing on the carrying, or assimilative, capacity of the ecosystem. In the context of monitoring, a key question, then, is: are there indicators that can serve as a measurement of how close an ecosystem is to some threshold, or that can serve as early warning signals of impending structural of functional "surprises"?

If we fail to detect ecosystem changes and remedy the cause in time, the ecosystem can become altered; often the changes that result are considered to be socially unacceptable, viz. the system is now "degraded". At this point, efforts to restore the desired system structure and function may be required. Monitoring, and the use of associated indicators, can play an essential role in this process by not only helping quantify the degree of reclamation success, but also by assisting in the evaluation of failed reclamation efforts. In this way, monitoring may be useful in designing programs to help reverse undersirable effects of man's activities.

4.2 Question to David Bernard (from Doug Evans)

Q. Given that most scientists have either strong vested interests or very poor judgement, how do you decide which subset of issues (or interactions) should be studied? (Note that there is a strong selection process in deciding

which scientists participate in a given adaptive management workshop!)

R. First, we get a list of all possible indicators/actions. In this phase we are allowing everyone to put in anything they want. Then we start asking "Why must we measure this"? People with vested interests must defend their suggestions to, and within, the group.

Question to Dave Bernard (from Roy Kwiatkowski)

Q. How does one establish when one has enough information to establish a baseline. There are seasonal and long term cycles compounded onto long term trends. Yesterday's trend is today's noise. For various systems, is there a "rule of thumb" for how long one must sample to establish a base line?

R. Practical baselines are, to some extent, arbitrary. This is to say that we often must establish a "baseline", despite the fact that we know that there are occasional, natural events that affect the system and influence our measurements. Perhaps it is realistic to suggest that a baseline be established in the context of lifetimes.

Question/Comment to Dave Bernard (from Mark Richardson)

Q. A comment regarding indicators at different level of organizations (biochemical, cellular, tissue, organic species, population, ecosystems). Indicators at higher levels of organization reflect stresses and effects which occurred in the past. Indicators at lower levels of organization can be used to predict and indicate what might happen at higher levels of organization in the future.

Question to Dave Bernard (from Judi Allen)

Q. In order to ascertain change or impact we must not ignore the importance of baseline data or benchmark ecosystems from which we can determine departures from

the norm. In the case of impact assessments, that consists of "pre-project" environmental measurements, whereas in state of environment reporting our baseline may be derived from monitoring of representative ecological reserves or national parks. How can we derive meaning from SOE trends without starting points or benchmarks for comparisons?

R. Without some basis for comparision, meaningful interpretation of SOE data is difficult, if not impossible. However, two points seem relevant: 1) even in the absence of historical or "baseline" data, inter-regional comparisons can be made, and 2) as long as SOE methods remain constent, the data reported in the first SOE report can be judged, later, in the context of later years' data. Determining what to choose as the "baseline" remains a difficult problem, though; do we choose conditions as they are now, or they were 10 or 100 years ago, or as they were prior to man's influence? One cautionary note: there are those who argue that even ecological reserves and natural parks are no longer "pristine" ecosystems, untouched by man.

Question to Dave Bernard (from W. Warwick)

Q. What time frames do you feel are adequate to establish a good baseline? I agree that good baseline data is crucial. As a palaeolimnologist, I deal in background time frames of thousands of years.

R. To establish an appropriate time frame for a baseline requires consideration of the dynamics of the system of interest. For example, the appropriate time frame for evaluating the state of the microbial environment is very different from the time frame for evaluating the state of the forest environment. In addition, you must be careful to recognize that even "baseline" conditions established over a "long" time period may not reflect occasional events that, in turn, may be very important to the dynamics of the system.

4.3 Rapporteur's Report of Work Group A.2, Indicators at Community or Systems Level, Gail Krantzberg

We attempted to make some clarification of how indicators fit into monitoring programs. Monitoring can be for a) prediction, and b) 'unnatural' changes in ecosystems. Monitoring includes: field sampling, data analysis, interpretation (ie. we must select indicators that are interpretable) and action (ie. we want to determine how to act based on the information gathered).

For the State of the Environment Report purposes, we focussed on the following:

1. indicators MUST reflect the SOE.
2. we did not address the ultimate goal of <u>how</u> we decide on which actions to pursue, based on indicators.
3. indicators MUST be understood by policy makers.
4. indicators should be used by scientists to compile the SOE report, but should still be interpretable by decision makers.
5. indicators will not be universal, i.e. we must examine a range of indicators.

In answer to the question of what is a SOE indicator?, we defined it as a measurement of the welfare of the system under study (eg. for forest systems, measures of productivity, nutrient status of soils, diversity of forested areas compared with undisturbed sites).

<u>Approaches to identifying indicators</u>

1. Consider the spatial range - the ecozone seems to be a reasonable level, but caution was expressed over applying indicators to the Pacific maritime and Montane cordillera ecozones which are particularly heterogeneous.

2. Consider multiple land/air/water use - different indicators for different problems.

3. Monitor land use changes.

Recommendations

1. There is a critical need to review and revise the 1986 SOE report in terms of suitability of approach, i.e. what "worked", what "didn't work", what got left out, etc. We need a formal mechanism for review.

2. Set up SOE network using key persons in each relevant department and install a formal mechanism to bring in external experts.

3. Interpret and assess utility of current, existing indices.

4. Establish a network of fixed monitoring stations taking into consideration permanence, new sites, and putting specific focus on existing networks for air, forestry, agriculture (ie. different land use). Consider both reactive networks (problem oriented), and diagnostic networks (long term monitoring), and integrate new and more appropriate indicators.

5. Continue to analyze existing data for utility, applicability.

6. Install a mechanism to introduce new approaches to assessing the SOE.

7. Research and development initiatives were recommended.

5. CHEMICAL INDICATORS

5.1 Introduction to Chemical Indicators, Using the Example of Soil Chemistry as applied to Agriculture, Dan Pennock.

The decline of organic matter levels in agricultural soils and the related deterioration of soil structure are fundamental to the degradation of soil quality in Canada. The impact of these two processes causes major increases in production costs to farmers; moreover, they are major contributing factors to accelerated soil erosion, with a number of deleterious off-farm impacts.

Soil Organic Matter and its Ecological Role

Organic substances in the soil ecosystem can be classified into two pools: readily decomposible biochemicals, which are converted by microbial activity into a major nutrient source, and a biodegradation resistant fraction, which provides a reservoir of chemically reactive materials for physico-chemical processes.

Studies on soil organic matter decline have primarily used soil organic carbon levels, which are relatively easily assessed, to document the decline. Although the assessment of specific organic fractions offers more precise documentation of the decline, the fact that such procedures are complex and laborious argues against their use as routine indicators.

Soil Organic Matter and Soil Structure

Soil structure is the result of the arrangement and interaction of inorganic and organic components into aggregates composed of pores and soil solids. The state of aggregation of soil influences biological production greatly, and the resistance of aggregates to dispersion and transport is a major control on soil erosion.

The degree of aggregation is strongly correlated to the organic matter content of a soil. Fungal mycelia and plant roots provide structual support for aggregates, while chemically reactive fractions, especially soil

polysaccharides, are important chemical bonding agents.

Reseachers have commonly used bulk density (mass of soil per unit volume) and the percentage of water-stable aggregation to assess the degree of structural deterioraton. Although several authors have argued that these are inadequate indicators, the alternative methods suggested are far more difficult to measure.

Decline in Organic Matter and Soil Structure

Numerous studies have documented declines in soil carbon levels of 30-60% over the period of cultivation of Canadian soils. Additionally, a decline of 20-30% in major nutrients such as nitrogen and phosphorus has also been observed. Comparisons among the studies are difficult, however, due to the lack of a standardized field sampling and laboratory analysis programme.

The observed declines are due to five major causes: 1) A horizon disruption during clearing; 2) crop removal; 3) increase in the mineralization rate; 4) loss of native biomass input; and 5) the physical removal of organic matter by erosion. The latter loss intensifies with time due to the deterioration of soil structure cause by the loss of organic matter and tillage practices. Although a new equilibrium between agriculturally-reduced organic inputs and soil organic matter levels should be reached, the acceleration of erosion may cause continued losses of organic matter from the system.

Limitations to the Use of Organic Matter Levels and Soil Structure as Ecological Indicators

The existing studies clearly document the deterioration of Canada's soil resources. Extension of the data pool is, however, difficult for the following reasons: 1) lack of a consistent field sampling and laboratory analysis program; 2) inadequate documentation of inherent spatial and temporal variability of organic matter levels and soil physical properties; and 3) lack of information from specific regions of Canada.

The lack of information on points 1) and 2) also limits the assessment of the impact of new management techniques on organic matter and soil structure decline, and, perhaps most importantly, prevents the adoption of possible solutions to a problem that relatively few realize exists.

5.2 **Question to Dan Pennock** (from Doug Whelpdale)

Q. If we were to use organic content of soil as an indicator, how many samples would be required for Canada? At what frequency would you monitor?

R. 1) As a general indication of the number needed, I believe it would be in the range of about 10,000. It would differ depending on the sampling program adopted.

2) To establish a baseline, a "one-time" sample is required; for a monitor of changes in environment, a sampling interval of approx. 5 years would be appropriate.

Question to Dan Pennock (from Terry McRae)

Q. Is there a general consensus within the soil science community about which indicators (ie. significant parameters) should be used to assess soil quality?

R. Unlike aquatic ecosystems where there appears to be considerable controversy regarding indicators, for soils we always seem to be coming back to the same indicators, organic matter, wind and water erosion, acidification, salinity, bulk density. I think the consensus exists, and the evidence for this lies in the various federal, provincial, and university publications which report the same group of problems.

Question to Dan Pennock (from Tom Brydges)

Q. Why is the oxidation rate of organic matter increased after clearing and ploughing? Wouldn't organic matter on the surface be oxidized faster than when

it is mixed up?

R. The increase in mineralization (through various reactions) occurs due to an increase in microbial activity. The microbial activity increases due to 1) increased aeration due to ploughing and 2) increased temperature range due to alteration of microclimate (among other causes).

Question to Dan Pennock (from Dave Bernard)

Q. 1) Can the input of organic matter (O.M.) from external sources offset the organic matter lost through erosion, i.e. if the ratio of loss/ input = 1, is the soil "safe"?

R. 1) The input of sufficient organic matter to offset the erosion loss would halt the overall decline of organic matter; however the quality of added materials (crop residues, animal waste) will probably not match the quality of the organic matter lost.

Q. 2) Will the new O.M. be incorporated into the soil matrix?

R. 2) Most types of recently added O.M. will not be incorporated - it is not decomposed sufficiently to yield chemically reactive elements. If it can be retained on the soil, microbial decomposition will yield aggregating agents within a few years.

5.3 Rapporteur's report of Work Group A.3, Chemical Monitoring, Magda Havas

We defined a chemical indicator as anything that was measured/determined as a chemical substance, even if it was a biological product (eg. chlorophyll).

Examples of chemical indicators in aquatic ecosystems.

Nutrients:	Dissolved Oxygen, Biological Oxygen Demand Nitrogen, Bio-available Phosphorus/Phosphate Chlorophyll (correlate of Phosphorus) Suspended Solids
Acidification:	pH, aluminum, acid neutralizing capacity (ANC) transparency The season is critical for certain measurements, of acidification stress.
Salt Stress:	Conductivity Sodium Chloride Bicarbonate Nitrogen
Metals:	Measures should be made in sediment profile
Organochlorines:	Measures should be made in biota not in water.

We recognized the role of chemical indicators in recording the present state and predicting the future state of the environment. We discussed chemical indicators of air pollution and water quality.

Approaches to chemical monitoring

(i) monitor 25 chemical pollutants recommended by government.

(ii) use various indices related to use of the air or water
- drinking water, fishery
- general water quality.
- toxicity of chemical (eg. index of 1 to 100 meaning poor to good

An index gives an overall picture of water quality. It is a good integrator/synthesizer. Indices should relate to base line and should highlight change. When using indices, we should allocate priorities and identify cause/effect whenever possible.

We then tried to answer the questions concerning chemical indicators. Points that came out in the discussion are as follows:

(1) Is nutrient leakage an indication of ecosystem stress?

Yes this is a good indicator but a good baseline is needed. Loss of nutrients can be used as an early warning indicator. Information can be used for both terrestrial and

aquatic ecosystems. It is valuable to have measurements for: calcium, magnesium, phosphorus, nitrogen, aluminum.

2) Can accumulation of chemicals in a system be used to monitor change?

Yes, buildup of CO_2 in atmosphere and accumulation of metals in soils/sediments are two examples. We can relate such accumulation to dysfunction but we need good research to answer the question of "effect".

(3) Are fluxes of nutrients and toxic chemicals useful as indicators?

Yes, but we must separate signal from noise (baseline/reference) (eg. emission flux Sarnia, INCO). Fluxes are not useful if natural flux exceeds man-made flux. Flux is more difficult to measure than concentration/accumulation parameters.

(4) Can elemental speciation be used as a chemical indicator?

Elemental speciation can be useful, but may be difficult to measure. For some problems speciation is essential to determine potential biological response. (eg. dioxins, forms of mercury, aluminum). The simplest separation is total vs dissolved or particulate but often more specific chemical speciation may be necessary to access bioavailability (methylation of mercury).

(5) Are certain interfaces important in identifying and monitoring problems?

Yes. The air/soil interface is the site of atmospheric deposition of air pollutants. It is also the site of seedling establishment, and decomposition. The water/sediment is difficult to measure but tells us whether sediments act as a "source" or a "sink" for pollutants. The air/foliage interface may relate to direct effects of air pollutants. The relative importance of the air/water interface varies with the pollutant. It may be very important for oil spills but less important for air pollutants. Interface measurements may help to explain processes.

(6) Is microbial activity a useful chemical measurement?

Yes, it can integrate responses but is not specific (eg. respiration, ATP production, decomposition, N-fixation, enzyme activity). Microbial activity may be quite variable therefore we need good baseline data.

6. INDICATORS AND ASSESSMENT OF THE STATE OF FISHERIES

6.1 Introduction to Assessment of the Fishery Resource, Henry Regier.

Speaking personally, one of my main pre-occupations in 30 years of professional work has been to help develop "balanced information services". As an undergraduate I helped with the classification of streams using biological indicators. As a graduate student I was introduced to the powerful role that indicators and indices played in management through Homer Swingle's work on farm-ponds. As a fledgling scientist Richard Ryder infected me with his indices in the field of fisheries limnology. And so on.

Any "boxes and arrows diagram" of an organization's decision making structure and process contains components related to information services or "intelligence". Figure 6.1 is a simplified sketch of such diagrams, here distorted to permit emphasis on balanced information services as a subsystem of the larger organizational system.

As it applies to a government agency, the central triangle contains the relevant senior politicians, civil servants, regulatory and law-enforcement people, as well as the people being "managed". The information system is shown here as three interlinked balloons, each of which represents a primary and different function. Each information function "feeds" on the others, predominantly as shown by the arrows. Each function serves management in a different way for different purposes.

Reliable information is based on valid understanding derived from proper scientific research: this conventional wisdom will go unchallenged here. Hence we can take the research function as a starting point, as the primary generator of understanding and information.

Figure 6.1 **A Technical Information System**

Research that purports to deal with parts of the real living world, in its state of being and becoming, should place roughly equal emphasis on three interrelated activities: mapping, monitoring and modelling. This generalization applies to the cultural anthropological as well as to the natural ecological aspects of the living world.

Monitoring provides data on how some feature or phenomenon of interest varies through time in some specified locale, (ie. trend-through-time data). Mapping provides data on how some feature varies over space at some point in time, (ie. an abstract snapshot picture of some selected space). If monitoring is done on a fine geographic grid, its data can be used to provide a sequence of maps. Similarly if mapping is done frequently, it can provide trend-through-time data for particular locales. The complementarity can become complex, as when the population features of a fish stock are monitored while its progress in migration is mapped.

Modelling seeks to interrelate data obtained from monitoring and mapping of a number of phenomena that appear to have some causal interconnections of

special importance. Modelling also draws upon results of experiments in which researchers use simplified microcosms of the real world to test hypotheses concerning causality. Experimental results with microcosms demonstrate what can happen in the real world of macrocosms; modelling of real world phenomena seeks to determine what does happen. To repeat: to yield understanding particularly useful to management, researchers must study the natural system, the cultural system and how the two interact. Mapping, monitoring and modelling must each have its natural, cultural and interactive dimensions.

The research process, the empirical data and scientific understanding will generally not be of immediate direct interest to management. Leading politicians, admininstrators and users will have other priorities than to try to understand "research". Usually they will not have been educated in this field, although there are exceptions. Practical justification for research will come largely from information that the researchers can deliver to the interpreters, assessors and planners. An agency may sometimes support a research capability as a kind of status symbol, in which case the research need not be particularly relevent to management concerns. To the extent that such symbolic research is relevant, it should be generally "supportive" of management biases and not raise embarrassing questions. Like mistresses, such researchers can be expected to be treated well if they remain discreetly in the background.

Researchers within a balanced information system that is well-integrated into an organization's decision-making process will nevertheless need to be active in networks of research that transcend the agency. Much relevant information and insight will enter an agency, at very little cost, from other organizations through the research component. The benefits of such networking are often undervalued by managers. Or such networking may be suppressed by incompetent or insecure management officials who fear new information. Of course, some research approaches may be biased against the dominant ideology of

management, in which case constraints on such research may seem more justified.

The main route by which insight and information from research enters into the management process is through planners, interpreters and assessors, (the second baloon in Figure 6.1). The information will be organized quite deliberately in a form thought to be directly relevant to the interests and needs of management. The packagers and communicators need to be well-informed on what researchers have to offer and what would serve management. This function is sometimes called "transfer science", which may be an abbreviation of "transfer of scientific information into a management setting".

As transmitted to management, the information may superficially appear to be simple and therefore unsophisticated. Not so. Generally the information will be in the form of indicators or indices that contain much of the more relevant information available within the researchers' more complicated data series and maps and within their more intricate models and inferences. To be successful within the "science transfer" function, the packagers and communicators will need to iterate between appropriately perceptive experts within management and within research. The sophistication may be different in kind and not in degree to that of researchers operating within their scientific networks.

A U.S. agency with responsibility for water quality has listed the following criteria for evaluating indicators and indices for possible use in the decision-making process:

- can be applied nationally or over broad biophysical regions;
- is logically related to harm caused by humans;
- is scientifically defensible;
- appropriate historical data are available for an adequate number of years, and such data will likely be collected in the future;
- the types of measurements used to assign value to the indicator or index are applied reliably and consistently;
- is simple to measure and interpret; and
- is generally quantitative in form.

This set of seven criteria is not included here as a specification of a necessary and sufficient set. It is reproduced to illustrate current thought on how information should be packaged for most effective communication for management purposes.

Planners have a key role in helping to organize the flow of insight and information from researchers to managers, but also in helping to put in place the evaluation function, (the third ballon in Figure 6.1). "Evaluation" may occur as a progam review or audit, a hearing by a legislative committee, a commission of enquiry, a court action, etc.

Where evaluation is done regularly and not in a crisis mode, management may rely on appropriate "performance indicators" that are based on data collected routinely. The appropriate indicators and indices are based on managers' expectations of the consequences of actions taken on researchers' insights on how the natural-cultural system will respond to such action. As with a formal scientific experiment, the more precise the specification of the goal or expected result of the action, the more rigorous can be the evaluation of success or failure.

Management officials who lack confidence in their acts or who work to keep options open will resist making clear, unambiguous announcements of their intentions. To do so might make them vulnerable to an unflattering audit or review. Obviously there would be little demand for information particularly relevant to evaluation.

In cases where a program has caused serious problems, a major evaluation may be undertaken. Much more information may be demanded than is available in the form of routinely collected performance indicators. A major initiative in program-oriented research may be conducted over a year or two. Such an initiative is not likely to be under the control of the in-house research

establishment. Instead it will likely be conducted by a private consulting firm with authority to access the organization's researchers and information. Some new information will be collected. The various kinds of information will be analyzed and packaged using statistical methods, simulation models, Delphi process, etc.

A thorough-going external evaluation may be so unpleasant to the officials of an organization that they may subsequently decide to incorporate a self-evaluation capability into their decision-making process. Whether for this reason or some other, organizations and agencies are increasingly undertaking periodic self-evaluations. But relatively little attention has yet been devoted to development of information services, (ie. performance indicators, particularly relevant to this purpose).

With the aid of planners, the evaluation function should also address the general relevance and cost-affectiveness of the research function. There may well be a general tendency to interpret relevance of research too narrowly, and expect innovation too quickly. Each research group of any size should have its "skunk works", in the words of Peters and Waterman in their book "In Search of Excellence". Some of the more brilliant and innovative researchers tend to be erratic, irascible, childish, unkempt, and generally too offensive to be presented to senior officials. Researchers like this who have demonstrated useful creativity should be permitted to work in the semi-isolation of a "skunk works", on the condition that their creativity over time does contribute importantly to the organization's purposes.

Consider balanced information services in aggregate for some major responsibility, such as the purpose of the 1978 Great Lakes Water Quality Agreement: "to restore and maintain the physical, chemical and biological integrity of the waters of the Great Lakes Basin Ecosystem". Clearly we are not at all close to having the necessary and sufficient set of information

available now to achieve that purpose. Because of the unpredictability of natural and cultural processes, it would be silly to try to create a closed set of rationally coherent information. But surely we can do better, with respect to each of the three major functions shown in Figure 6.1. It is time now to close the loop, in the hope that a positive feed-back process may develop to produce more innovative and relevant information in a more cost-effective way. It should now be apparent that all of the foregoing amounts to an elaboration of a meaning of "experimental management".

In appendix D, a list of publications is offered rather immodestly as an example of efforts - by my colleagues, graduate students and myself - towards balanced information services. The primary focus is on fish and secondarily on aquatic ecosystems. Implicitly our efforts were devoted toward realization of Aldo Leopold's "land ethic".

6.2 Comment to Regier (from Hamish Kimmins)

I was interested in your comment that succession in aquatic ecosystems is often unpredictable and that aquatic systems frequently do not tend to return to pre-disturbance conditions in the way that forest ecosytems do.

Forests have the innate tendancy of forming or creating their own environment. Forests modify the microclimate and the physical and chemical conditions of the substrate as they grow. They accumulate essential nutrients from the enrironment into tight biogeochemical and internal cycles. They build up soil organic matter which improves soil moisture storage capacity, nutrient retention capacity, and soil architective (soil structure). These autotrophic changes are part of the driving force of autogenic succession and lead to the process of successional convergence. Although complete convergence rarely occurs, remarkably good examples of convergence towards a common climatic climax do occur in the warm humid ecosystems of the west coast where the "monoclimax"

theory or model of succession is a reasonable approximation of what happened prior to logging.

This tendency for forest ecosystems to recover from episodic disturbance means that environmental monitoring of forest ecosystems must be in terms of the intensity and frequency of disturbance, and the characteristic rate and pattern of recovery of the ecosystem involved.

6.3 Rapporteur's report of Work Group B.1, Fisheries, Patrick Bolger

We identified the most important variables, which should be examined, and the thresholds which could be used to alert managers in order to achieve sustainable management of the fisheries resource.

MOST IMPORTANT VARIABLES

Physicochemical Data

- sampling of standard physical parameters are essential e.g. flows, water levels, temperatures, etc.
- sampling of standard chemical parameters are also essential e.g. pH, oxygen, hardness, nutrient levels, etc.
- sampling of known contaminants should be carried out to determine trends of increasing or decreasing levels.

Biological Data

- more emphasis should be given towards the field collection of biological data to assist in assessing the quality of the environment e.g. examination of reproductive success, morphological changes, histopathological changes, diversity of benthic invertebrates, etc.

EARLY WARNING INDICATORS

Physicochemical Indicators

i) Hypolimnetic Oxygen Depletion

- changes in the hypolimnetic oxygen levels can lead to major ecological consequences e.g. Lake Erie.

ii) Trend of Increasing Contaminant Level

- a trend of increasing contaminant levels can serve as a warning of more serious environmental problems e.g. pH decline in lakes and streams.

iii) Habitat Destruction

- loss of habitat by pollution or physical destruction can result in reproduction failure. e.g. loss of spawning beds and wetlands.

Biological

i) Reproduction

- since reproduction is the most sensitive part of the life cycle, look for failure of age classes, extinction of fish species, etc., e.g. shift in fish population in Lake Erie and extinction of Blue Pike.

ii) Morphological/Histopathological Changes

- look for tumors or lesions in aquatic organisms e.g. abnormalities in chironomids.

iii) Bioaccumulation

- look for bioaccumulation of chemical substances in aquatic life e.g. bioaccumulation of PCB's and DDT in Herring Gull; mercury bioaccumulation in fish.

iv) Diversity Changes

- look for shift in diversity of benthic invertebrates or other organisms e.g. Network Monitoring System/Index of Biotic Integrity (Carr).

v) Bioassay Testing

- look for response of organism to known or unknown toxicants.
- useful as early warning indicator of toxicity in industrial effluents.
- difficult to determine optimum test organism and conditions of test.
- the value of bioassays in legislation was discussed e.g. effluent regulations, MISA Program, etc.

7. INDICATORS AND ASSESSMENT OF THE STATE OF FORESTS

7.1 Introduction to Assessment of Forests, J.P Kimmins

There is probably no more characteristic a feature of forest ecosystems than that they change over time. This change is the result of a wide variety of processes, most of which are "natural" but some of which are human-induced (either "unnatural" processes, or simply an increased frequency, intensity and/or extent of "natural" change). Monitoring and predicting the effects of human activity on the condition of forest ecosystems thus involves the separation of the effects of naturally-caused disturbance on the recovery of ecosystems from comparable and/or dissimilar human-induced changes

Factors affecting the condition of forest ecosystems include:

1. Climate change: both natural climatic fluctuations and human-induced alterations in climate.
2. Allogenic successional processes that involve geomorphological processes largely unrelated to biotic influences.
3. Autogenic successional processes caused by a variety of ecological processes.
4. Biogenic successional processes caused by animals and plant pathogens which may reflect natural fluctuations in these biota or human-induced changes therein, or introductions/eliminations thereof.
5. Changes caused by alterations of atmospheric chemistry.
6. Changes resulting from the episodic disturbance caused by wind, fire, logging, and/or forest clearing for agriculture or other land uses.

Most changes in forest ecosystems tend to be initiated by episodic events such as clearcutting, wildfire, windthrow, or insect outbreak. The response of an ecosystem to such disturbances, and its recovery therefrom, will depend on the climate, soil, topography, ecosystem condition (i.e. nutrient and soil organic matter reserves), vegetation type and development, faunal characteristics of the ecosystem, and on the intensity and extent of the disturbance. Many of these are dependent on the time elapsed since the previous disturbance.

The impact of episodic disturbance and the recovery are thus under the control of a wide variety of factors and are correspondingly difficult to predict accurately if based on simple assessments of the ecosystem or a small set of "ecological indicators".

Monitoring and predicting the short, medium and long-term consequences of episodic events on ecosystem conditions will thus involve approaches that differ from monitoring the effects of agents of more continuous chronic disturbance such as acid rain, air pollution or "greenhouse effect" climatic change. Monitoring episodic disturbances requires a comparison between:

1. the post-disturbance condition and temporal patterns of recovery, and
2. the expected pattern of temporal change in ecosystem condition associated with the historical frequency, intensity and extent of "natural" disturbance (i.e. the baseline temporal pattern of change).

Unfortunately, we generally do not have the necessary empirical data to adequately define this baseline pattern. Because gathering such data will require many decades and considerable expense, monitoring the state of the forest environment in the interim period will require the development of site-specific, ecosystem-level models.

Ecosystems models, once calibrated and validated (to the extent that this is possible) can be used to produce a simulated baseline of ecosystem change against which monitoring of actual changes in ecosystem structure and function can be compared. Monitoring of untreated, undisturbed forest environments will create datasets that can be used to validate and, where necessary, modify (improve) these models. The models can also be used as "best-estimate" gaming tools to explore the future consequences of a variety of alternative forest policy decisions and management strategies designed to maintain and/or improve forest environmental condition. The required knowledge, the technical expertise and the computer hardware needed to construct and use such models now exists,

and several models of this type (e.g. FORCYTE) have already been developed. The design of monitoring networks and data collection activities in forest ecosystems should be guided to a considerable extent by the models that are to be used in conjunction with the data.

Because of the site-specific nature of forest ecosystem response to disturbance, models thereof and the collection of environmental monitoring data to describe the response should be site-specific. This will require that the Canadian forest environment should be stratified into broadly homogeneous units, such as the biogeoclimatic zones of B.C., Alberta, and comparable units in Ontario. The present Ecozones of the SOE report should be subdivided into biogeoclimatic zones, and monitoring should be conducted in each zone. This will inevitably require a higher intensity of monitoring in the physiographically, climatically, and pedogenically more diverse western two provinces.

The choice of the model to be used as a tool by which to monitor and predict the state of the Canadian forest environment should be dictated by the objectives of the monitoring program. As a minimum, such a model should be able to predict soil organic matter and nutrient dynamics, vegetation biomass, structure, growth rates and chemistry, and wildlife habitat. With appropriate modification, such an ecosystem model could be used to monitor and predict chronic disturbances such as acid rain, air pollution and atmospheric warming.

The uses of simple ecological indicators in forest ecosystems will probably be limited to the monitoring of chronic as opposed to episodic disturbance effects. Lichens, humus form, soil animals, and/or soil solution chemistry (monitored by resin bags) would be candidate "indicators" in this regard.

Indices such as NSR ("not satisfactorily restocked") are useful as a description of the "present condition" of forests relative to some management or economic criteria, but do not accurately reflect the "quality" of the forest environment. NSR does not define how rapidly the ecosystem will change to some other condition, nor its productivity in the present or in the future.

NSR may represent a temporary or a prolonged arrest in successional development or it may represent a "degraded" condition of the ecosystem. The index does not differentiate between these conditions.

In conclusion, it is time for Canada to emulated activities in the U.S. and at IIASA (International Institute of Applied Systems Analysis in Austria) in continental-scale modelling. Such modelling can provide a means of harnessing the date from large-scale monitoring programs and a wide variety of research activities in the service of describing the present and predicting the future state of our forest environment.

7.2 Questions to Hamish Kimmins (from Michael Wong).

Q. 1) With regard to nutrient losses and ecosystem productivity, how does herbicide application for site preparation affect these outputs, according to the model? and 2) If the time frame was taken over 40 years, as in the Swedish study, what would you predict will happen?

R. Nutrient Losses. Our recent study in B.C. of a glyphosate spray against the brush community on an eight year old clearcut revealed a three times increase in soil solution NO_3^- for 12 months following the spray, declining to pre-spray values within 24 months. Streamwater NO_3^- levels were raised seven times, but from a lower starting value, with peak values about 1/3 of the peak soil solution levels. Stream levels remained elevated for at least two years.

Nutrient leakage as a result of herbicide spray is related to the extent of vegetation reduction.

FORCYTE predicts that any unused NO_3^- will be leached, and therefore its prediction of NO_3^- leaching is sensitive to the size of the mineral nitrogen pool, the NO_3^-/NH_4^+ ratio, and the extent of plant uptake demand. The model does not represent in-stream nutrient processing and thus will not predict stream concentrations. We found that NO_3^- and $P_2O_4^{=}$ additions to the stream were

taken out of solution in the 100 to 200 metre downstream reach, depending on stream flow.

Regarding the Swedish Study, the experiment was conducted on poor-medium sites. The model predicts this type of behaviour fairly accurately.

7.3 Rapporteur's report on Work Group B.2, Forestry, Tom Brydges

Questions on Forestry. 1) How do we separate "normal" from human-induced change in forests? 2) How can we predict long-term changes based on backward-looking science? 3) How do we decide on the acceptability of changes?

1) Separation of normal from man-made change

a) Design a monitoring network of stations over areas of different pollution levels and different stand ages; include dendrochronology.

b) Review symptoms of decline and chemical composition of the wood. Compare ecological and eco-illogical symptoms.

c) Establish long-term monitoring of forest growth in areas subjected to experimentation. In some cases we only need to follow what industry is doing. The "acidification" experiment has been going on for 70 years.

d) Inventory the forest areas under different conditions (eg. cut, planted, burned etc.) as the first SOE did.

e) Monitor nutrient dynamics and leaching of nitrogen, phosphorus, calcium and other soil ions. Determine if some are in short supply.

f) Measure leaf area and growth of key trees species (leaf area is related to sap-wood area).

g) We also need a measure of wildlife diversity in forests.

2. How do we predict long-term changes?

a) Combine monitoring and research data into models and apply "best-educated-guess" approach.

b) Research and monitoring must go together.

3. How can we evaluate the changes?

a) Must first decide on the land-use goals (eg. fiber, wildlife, recreation)

b) Technology will change the interpretation (eg. forest growth will be

increased by new technology so the inventory will change). B.C. can double growth rate. There will be conflicts regarding use (eg. logging and burning vs. preservation).

4. Other Factors

a) We have not learned from agriculture about crop rotation. As our forest "crops" deteriorate, we change the use of the product and this is a continuing practice.

b) History has shown that we use our own forests and then go and get "somebody elses'". We are running out of places to go. Now we must depend on silviculture to supply greater demand from exising forest areas.

7.4 Questions to Forest Group (Kimmins responded), Terry McRae.

Q. What are the "technologies" or management strategies which would allow B.C. to double its forest productivity?

R. Prompt regeneration; full stocking; pre-commercial and commercial thinning; fertilization; whole-tree harvesting; shorter rotations; genetically-improved stock.

Q. We read very little about the forestry industry's position regarding the problems facing forestry (eg. the effects on forests of acid rain). Foresters are strangely silent. What is the explanation?

R. Most forest industry in Canada is based on "tenant farming": harvesting an existing crop that they had no hand or investment in creating. Rarely are there any institutional incentives (corporate, governmental) to have more than a short-term perspective. Foresters' concern is with present and short-term future timber supply, staying in business, and competing in the marketplace. Only the larger companies with the bigger "stake" are interested in these longer-term issues.

Additional Comments by Kimmins

Nutrient Leaching from Disturbed Ecosystems. The conventional approach of monitoring dissolved nutrients has significant limitations as a measure of the loss of nutrients from the land. Many of the solutions of nutrients entering the stream are rapidly taken out of solution by in stream geochemical processes. The alternative approach of sampling soil solution chemistry using tension or tensionless lysimeters is helpful, but may only sample saturated flow. A better method of sampling average soil solution chemistry over extended periods may be the use of buried resin bags. A mixture of anion and cation exchange resin beads are placed in fine mesh bags and buried at the soil depth of interest. The bag(s) are recovered after some sampling period, eluted, and the resulting solution analyzed for anions and cations. This is an easy and low technology way of comparing soil solution chemistry from site to site and year to year.

The question of Crop Rotation. "Unsuccessful" silviculture in coastal B.C. permits natural succession including a period of occupancy by red alder, to rebuild soil fertility, but delays the growth of a new timber crop. "Successful" silviculture short-circuits succession, eliminating shrub and deciduous tree stages. This minimizes the time to produce the next coniferous crop, but may increase the need for fertilization if forest growth is to be maintained.

The U.S. foresters in the PNW are investigating crop rotation of alder-AF-alder-AF to duplicate the desirable consequences of natural succession within the framework of crop production. If fertilizers become more expensive, this trend will probably be followed in western Canada.

Questions to Forestry Group, Tom Brydges asked for comments on the following:

What are we trying to protect? Protection of species seems to be a key factor in environmental protection. Should we take into account any real or

likely loss of species due to some action?

R. P. O'Hara - Canadians' concern for the environment is primarily based on concern for health.

R. J. Allen - I disagree. The public response to Mme. Blais-Grenier's suggestion that national parks could be open to mining and lumbering was overwhelming. It suggested that there are strong feelings in Canada for wilderness preservation.

R. T. Hutchinson - It seems that in Canada our public focus is on habitat or ecosystem protection rather than on preservation of individual species. The recent focus in Ontario on Bacchus Woods, and in B.C. on South Moseby, Lyell Island, are indicative of this. The National and Provincial Park Systems are also a reflection of a collective desire to maintain wildlife habitat and beautiful natural scenery. Interestingly, the public has a deep concern even if they will never see the places they want preserved or safeguarded (eg. the arctic). Our concern for endangered species is there but the level of information and education on Canadian ones is only just picking up. People are better aware of the Giant Panda, the Indian tiger etc., than they are of endangered Canadian species. Also, the Endangered Species Act is very weak on plants.

Question P. O'Hara to T. Brydges.

Q. We have learned that ecosystems are being altered by some of our activities such as forest fire protection, and replanting species that we think are more valuable, but which in reality changes the natural ecosystem. What are we really trying to do?

R. It is difficult to think in terms of monitoring pristine ecosystems since we probably don't have any - or very few. As you say, almost all of the globe has experienced some man-induced change; I think the goal should be to protect species and prevent further loss of species. This would certainly involve

species and prevent further loss of species. This would certainly involve keeping some of the least affected habitat in the most pristine condition possible - but we wouldn't be deluding ourselves into thinking we were protecting a fully pristine condition. Or we could rule out further human activities in the protected area. As was pointed out, cutting a few trees in a "protected" area may be fully justified in terms of "ecological preservation". It raises a very difficult issue that needs more thought and discussion by experts.

8. INDICATORS AND ASSESSMENT OF AGRICULTURAL SUSTAINABILITY

8.1 Introduction: Methods of Assessing Agricultural Sustainability, Ted Huffman

Sustainability is emerging as one of the most fundamental concepts for assessing the overall state of an agricultural production system. Essentially, this concept assumes that if a production system is sustainable indefinitely, then it is acceptable. But almost any system is sustainable if sufficient resources are committed to it! So it's obvious that an uncritical adoption of the idea is not acceptable. Over the past several years a growing number of philosophers, ecologists, environmentalists and agriculturalists have been attempting to establish what sustainability is and how it can be measured with respect to agriculture.

I prefer the definition put forward by Gordon Douglas in his essay "The Meanings of Agricultural Sustainability" in which he states that sustainable agriculture is "any combination of circumstances which permits farmers to meet future demands for foodstuffs without imposing on society any real increase in the social costs of production". On a more fundamental basis, we're looking for systems that can maintain production without increasing the amount of inputs per unit of output, and in which there is no degradation of the production mechanism.

Presumably then, we know what we are trying to assess; the problem of how to assess that - of how to measure our progress in achieving sustainable systems - is another matter altogether. The problem is that there are a number of different aspects to the question of sustainability of agricultural systems: 1) there is the concern over maintenance of the physical base of agriculture - the factory, if you will - which in this case, at this time is almost exclusively the soil. This aspect is receiving a concentrated effort by the agricultural profession and is obviously the one in which we have made the most progress.

2) a second very important aspect is economic sustainability - and this relates to the supply-and-demand mechanism that stimulates production. In order to be economically sustainable, a system must generate enough income to at least cover expenses over the long term - that is, the system must produce without incurring an ever-increasing debt load. Measuring viability over the short term is well developed - we have indicators such as annual net margin and return to labour. However, the assessment of long-term viability has received much less attention. Recently, as we have begun to look at agriculture as an investment opportunity, indicators such as running debt/equity ratios and capital use efficiencies have become of interest. How these relate to sustainability is still only conceptual.

3) the third aspect of sustainability relates to social conditions, and assumes that social sustainability requires the maintenance of agriculture as an acceptable occupation and the maintenance of consumer acceptance of products and methods of production. There has been almost no consideration of how to measure this, but it is increasingly being recognized under the guise of such terms as stewardship, vitality of rural communities, family farms, organic produce, animal welfare, health hazards of farming and farm stress. It will probably be some time before anything more than an unquantifiable "impact on sustainability" is referred to.

4) the last - and perhaps the most important - aspect of agricultural production sustainability relates to the intrinsic strength of different production systems. That is, the inherent ability of a system to resist damage from external forces or from changing conditions. Although there are a number of different external conditions acting on agricultural production (climate,

weather, markets, input supply), and there are a number of different terms that can be used to describe a systems response (sensitivity, vulnerability, adaptability), there are only two that have recieved much attention; risk and flexibility. Risk has been studied from the perspective of how farmers manage it, and flexibility has been estimated with respect to the number of different cropping choices available to a farmer. It is assumed that lower risk and higher flexibility indicate more sustainable systems.

Summary. Sustainability of agricultural production systems is affected by a whole variety of internal and external factors - and the assessment of sustainability must incorporate a similarly wide range of indicators.

To evaluate physical sustainability we must focus primarily on changes in topsoil depth, soil organic matter content, structure, texture, bulk density, pH and salt content, and we must assess slope steepness and length, cropping practices, and climate.

Economic sustainability centres on the viability of farming operations and is measured in terms of annual net margins, return to labour, debt/equity ratios, and capital use efficiencies.

Social sustainability refers to the maintenance of a healthy, satisfied and committed agricultural workforce, and entails concepts such as stewardship, pride, and social acceptance-factors that are particularly difficult to evaluate objectively.

System sustainability relates to the ability of a production routine to maintain its integrity despite external forces or changes. It is evaluated in terms of the systems flexibility, adaptability, vulnerability, sensitivity, and its level of risk.

It is obvious that a great deal needs to be done in order to bring these concepts to workable measures of sustainability. Particularly critical is the

need for an extensive documentation of the types and locations of present cropping systems and the establishment of their relationship to physical, economic, social and environmental conditions.

If we can adequately mobilize our resources to determine which practices are sustainable and which are not and how to change those which aren't, we'll have come a long way toward reaching a healthy and harmonious agricultural production industry.

8.2 Rapporteur's Report for Work Group B.3, Agriculture, Darrell Piekarz

Recommendations. Recognizing that environmental quality considerations generally lie outside of the design criteria of historical soil classification surveys, a reallocation of spending on these surveys is required to identify soil quality differences. Initially, new monitoring of agriculture land should include: 1) A national survey on a county basis of trends in the levels of soil organic matter; measures of nutrient content; measures of erosion; and 2) a national survey using remote sensing technology and statistical information from the Canadian Census of Agriculture to locate and monitor cropping practises. It is believed that these recommendations would be supported by soil scientists and farmers.

The agriculture Work Group was asked to consider two questions:
1) Identify the most important variables which should be measured to ensure sustainable agriculture ecology and 2) Identify indicators of the resilience of soil ecosystems.

Discussion. The viability of agricultural systems is traditionally measured through productivity. Soils are considered a medium for growing crops, and farmers make up for soil deterioration and economic pressures by increasing the inputs of nutrients, adopting machine and energy intensive methods, of production, adding pesticides and developing new varieties through genetic

manipulation. These are usually set to achieve maximum yields.

Agriculture is generally not practised in a manner that returns soils to their original condition. High yields can be maintained with high input as long as topsoil is present; however, yields decline when subsoils are farmed. Topsoil regeneration can occur but that usually requires a reduction in cropping intensity. It is the premise of those who are developing new cultivars that this may be delayed indefinitely.

This led us to consider cultural factors. In answer to the proposal of leaving large tracts of land out of production until the top soil has regenerated, the disruption of human communities and implications for national economics (at least for Canada) precludes this option.

To answer the first question, the commonly understood measures of soil quality and thus of sustainable agriculture, are organic matter content, soil nutrient levels, pH, salt content and depth of topsoil. Resilience of soil systems was not precise enough, and the second question was re-defined by the group to ask if there are distinct points beyond which no cropping is possible. It was agreed that you could determine this fairly precisely for the salinization process and for the loss of topsoil. Given new cultivars, these limits could be shifted. Clearly, urbanization of farmland is an unrecoverable loss. A return to more benign agricultural practices such as forage rotations, and the adoption of practices such as contour plowing, low-till cultivation and grassed waterways have the effect of maintaining soil quality at present levels (or at least slowing the decline in soil quality) while keeping yields at an adequate level. However, these methods will rarely restore the soil to original condition. Practices that can return soils to their original state are becoming more popular among farmers. The practice of "regenerative agriculture" explicitly aims to improve soil quality but crop yields are usually lower than with the conventinal high intensity common practices. Nevertheless, these

practices are seen by many to be a solution to the world soil crisis.

Information Sources. Although it is well known that soils can be stressed, little data or measurements of these stresses are available. In Canada, there is a small body of soil literature for the Prairies and very little else for the remainder of the country. A new technique using the Cesium^{137} isotope to measure changes in the organic matter of agricultural soils can provide a temporal measure. This technique is inexpensive and could be easily incorporated into monitoring programs. (See case study of Dan Pennock).

Agriculture Canada has conducted detailed soil surveys in each province on a county basis since the 1930's. These surveys provide a soil resource inventory most useful to a relatively small group of soil structure and taxonomic specialists. These inventories cannot be used to assess the soil quality in a region only in a general way, and they provide little interpretative information as needed for policy and planning.

Is it possible to obtain vital soil quality information from the farmers themselves? We propose that surveys be devised that would involve the farmer directly. Farmers could be trained in the procedures of taking soil samples and the analyses, (ie. for organic matter), could be done in a lab. One obstacle to be overcome would be the different vocabularies of farmers and soil scientists. Even so, more involvment by farmers was seen as a first step in getting them to learn more about soil management and crop selection and to assist with quality assessments. Environmental monitoring by volunteers is an inexpensive way to obtain information, but design and sampling protocols would require expert advice and some initial funding.

The group recognized that there is considerable institutional inertia and that current soil surveys done by governments reflect a particular mind set. The group concluded that innovations with the reallocation of money should be advocated.

8.3 **Comments to Darrell Piekarz** (from Hamish Kimmins)

Have bioassays of soil fertility been used to monitor soil fertility and site productivity in agriculture? The use of seedling bioassay (ie. tree seedlings grown in soil from different depths - 0-5cm, 5-10cm, 10-15cm) has been shown to be an expensive and often hard-to-interpret soil chemical analysis data.

Reply from Ted Hoffman

Bioassays are a useful complement to direct measures of soil nutrients. In the assessment of agriculture soil fertility, the broad measure used is crop yield. More precise experimental measurements are obtained from whole plant dry matter. Agronomists have found that under controlled conditions, dry matter yield is a reliable method of comparing soil fertility.

9. DISCUSSION OF NOVEL MONITORING

Michael Wong. I believe that the approach of having the original SOE report reviewed externally and the comments and changes taken into consideration is a good one, rather than your group submitting proposed changes for agreement or disagreement. I think the latter approach is putting the cart ahead of the horse, a comment which was repeated during the workshop.

Pam Stokes. Several examples exist of actual or potential data collection systems which involve volunteer (but not necessary non-expert) involvement (eg. bird census by ornithologists in U.K.; collection of leaves by school children; collection of water samples and subjective observations about lakes by cottagers; and farmers in soil surveys). This approach has some social benefits in that people feel involved and there is also potential for education and improved understanding.

Tom Brydges. Volunteer groups have been used effectively in the past. The key is for an agency, or individual scientist within agencies, to decide on a useful project and then carry it out. It may or may not need funding, but it certainly will need scientific leadership and that must be provided by the scientist/agency. Each case must be treated separately, there are very few general rules that can be applied.

Michael Gilbertson. It would be useful to use volunteers, particularly in local field naturalists' clubs, to collect presence and absence data. Also one could use data from trappers' associations (for mink/otter populations) and use carcasses for analysis of chemicals. Field naturalists' clubs could be asked to put up osprey platforms and to monitor long-term productivity.

There is a need for governments to put a small amount of resources into organizing these volunteer activities and to collate the information for publication.

On another point, how do you bring about the marriage of monitoring and research activities so that models can be prepared? Frequently there is a high enough level of organization that controls activities and budgets.

Tom Brydges. Combining research and monitoring is totally dependent on finding some scientist to do it. The exercise can be very productive if you can find somebody to do it. Too often scientists overlook monitoring data or reject the results on the basis of poor data quality. In fact you can make more use of the data than is generally done.

CASE STUDIES

FRESHWATER AVIAN AND MAMMALIAN PREDATORS AS INDICATORS OF AQUATIC ENVIRONMENTAL QUALITY, Michael Gilbertson, Commercial Chemicals Branch, Environment Canada. Ottawa, Ontario. K1A 0H3.

Governments and industries have become deeply involved in the maintenance and rehabilitation of aquatic environments to protect them from chemical degradation. To aid in this process millions of dollars are spent on collection of information on various aspects of aquatic environmental quality. An integral part of this information collection process involves the use of certain more highly exposed and sensitive organisms to indicate the integrated chemical stresses in a particular environment. The objective of this paper is to outline the advantages and disadvantages of four avian and mammalian predators, the bald eagle, osprey, mink and otters, as indicators of aquatic environmental quality and the kinds of information on these species that could be collected to make a defensible scientific case for regulatory action. The paper starts from the premise that if these species are present and maintaining their populations, then aquatic environmental quality is probably satisfactory.

The resources that have been allocated to monitoring, have for the most part been used to determine the levels of chemicals in various materials such as water, sediments, effluents, fish and birds. A much smaller portion has been used to investigate the actual effects of chemicals on exposed organisms. There is now a growing realization that in preparing a defensible scientific case to protect aquatic environmental quality it is essential to obtain data not only on levels of chemicals in the environment, but in cases of serious contamination, also on the toxicological effects that have occurred in indigenous organisms.

The criteria for selection of indicator species for monitoring exposure and effects of chemicals in the environment have been extensively reviewed and can be summarized under the following headings:

1. Tendency to accumulate high levels
2. Knowledge of migratory habits, range and distribution
3. Ease of sampling and handling and of undertaking field work
4. Knowledge of biology and physiology

Table II is a matrix of these criteria versus the four aquatic predators. Generally these four species have proved useful indicator organisms since they accumulate high levels of organochlorine chemicals and are sensitive to the toxicological properties of these chemicals. There is extensive knowledge about their biology, migratory habits, range and distribution, however the species tend to be fairly difficult to study in the field to obtain direct estimates of productivity and population size.

Table II contains brief information about the case histories of changes in populations and reproductive success in these four aquatic predators believed to be related to organochlorine compounds particularly DDT and PCB. The similarity of the changes between species and at widely separated localities reflects the critical susceptibility of the reproductive process in the life cycle of those species to the presence of chemicals in the environment.

The collection and analysis of monitoring data on levels and effects of chemicals in biota and in the environment is insufficient by itself to infer causality. In epidemiological research five criteria have been derived for discussing case histories that infer a relationship between a disease and a suspected agent. These five criteria (after Susser 1986) include:

a. time order - did the observed effect occur before or after the exposure to the supposed agent?

b. strength of association - what is the degree to which the supposed agent and the disease concide in their distribution?

c. specificity - how precisely does the occurrence of the disease or supposed agent predict the occurrence of the other?

d. consistency on the replication - how well does the supposed relationship persist when the results of different case histories are compared?

e. coherence - does the relationship cohere with preexisting theory and knowledge?

These stringent criteria have seldom been applied to studies of declines of population of animals supposedly caused by chemicals. A notable exception is the work of Newton (1979) who used them to discuss the relationship between eggshells thinning and the declines of various populations of avian raptors.

Table I MATRIX OF CRITERIA FOR SELECTION OF INDICATOR SPECIES VERSUS FOUR AQUATIC PREDATORS

	Bald Eagle *Haliaetus leucocephalus*	Osprey *Pandion haliaetus*	Otter *Lutra canadensis*	Mink *Mustella vison*
Tendency to accumulate high levels	Extensive data on accumulation of organochlorine compounds Levels high enough to cause population declines in several locations			
Knowledge of migratory habits, range and distribution.	Long term banding has been used to establish migratory habits and range. Long term changes in distribution caused by chemicals fairly well established.		Species not migratory. Difficult to establish range of individuals. Distribution well established.	
Ease of sampling, handling and undertaking field work.	Difficult and often unethical to sample. Time consuming to obtain productivity data.	Generally easier than bald eagle to sample and handle.	Large quantities of biological material available from annual trapping season. Long term population trends may be estimated from trapping returns. Presence and absence may be determined from characteristic scats but both species are secretive and solitary.	
Knowledge of biology and physiology.	Life cycle biology well established. Difficult to age adults but juveniles can be aged. Extremely sensitive to the effects of organochlorine compounds Kinetics of pollutants poorly known.		Life cycle biology well established. Can determine age of specimens by calcified layers on teeth. Kinetics of pollutants poorly known. Extensive laboratory studies of accumulation and effects of chemicals.	

Table II CASE HISTORIES OF CHANGES IN POPULATION AND REPRODUCTIVE SUCCESS OF FOUR AQUATIC PREDATOR SPECIES

	Location	Description of observed changes	Suggested cause	Reference
Bald Eagle	Great Lakes	Severe population decline and local extinction. Some recent recoveries.	DDT	Sprunt et al. 1973. COSEWIC, 1984, Postupalsky, 1978.
	Northwestern Ontario	Depressed reproductive success and subsequent recovery	DDT	Grier, 1982.
	Lower Columbia River, Oregon	Depressed reproductive success	DDT and PCB?	Anthony, (pers. comm.)
	New York State	Nearly extinct but supplemented by reintroduction.	DDT	Nye (1983)
	Florida	Depressed reproductive success and subsequent recovery.	DDT	Broley, 1958 COSEWIC, 1984
Osprey	Great Lakes	Severe population decline and local extinction.	DDT	Hickey, 1969 Madsen et al. 1982
	Connecticut	Depressed reproductive success and population decline and subsequent recovery.	DDT	Spitzer et al. 1978
Otter	Lake Michigan, Wisonc:in and Michigan.	Population decline near lake.	PCB	Kohn and Ashbrenner, 1984 Kubiak pers.comm.
	Lower Columbia River, Oregon.	Population decline	PCB	Henny et al. 1981
	Hudson River, New York	Suggested impairment of reproduction	PCB	Foley, 1985 and 1987
Mink	Lakes Erie and Ontario and St-Lawrence River	Suggested impairment of reproduction	Elevated levels of PCB	Proulx et al. 1985
	Hudson River and L. Ontario	Suggested impairment of reproduction	Elevated levels of PCB	Foley, 1985 and 1987
	Maryland	Suggested impairment of reproduction	Elevated levels of PCB	O'Shea et al. 1980

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INDICATORS OF ECOSYSTEM HEALTH AT THE SPECIES LEVEL AND THE EXAMPLE OF SELENIUM EFFECTS ON FISH, Peter Hodson, Great Lakes Laboratory of Fisheries and Aquatic Sciences, Bayfied Institute, Canada Centre for Inland Waters. P.O. Box 5050, Burlington, Ontario. L7R 4A6.

Abstract

Chemical monitoring of aquatic ecosystems provides a description of the potential chemical exposures of aquatic biota and a measure of the success of pollution control. However, meeting water quality objectives provides no assurance that aquatic biota are protected from the effects of unexpected chemicals, mixtures and the interactions between chemical exposure and environmental stress.

Biological monitoring is an obvious solution since aquatic biota will integrate spatial and temporal variations in exposure and the effects of all combined stresses. Top predators, typical of specific aquatic ecosystems (e.g. lake trout in cold water oligotrophic lakes) can provide an indication that certain environmental requirements have been met. As a bellwether, the simple presence of naturally reproducing, self-sustaining and productive conditions are not met, there is a clear sign of environmental degradation. The pattern of subtle shifts in population structure and performance may also diagnose poor quality.

Unfortunately, environmental and fisheries managers cannot rely solely on populations, communities or ecosystems to indicate chemical effects. The time lag between identifying a problem and finding a cause may allow a complete destruction of the resource that we wish to protect, particularly where chemicals are persistent.

A solution to this dilemma is biochemical monitoring, the measurement of primary or secondary responses of individual organisms to chemical exposure. Since all toxicity at any level of organization must start with a reaction

between a chemical and a biological substrate in individual organisms, these responses will provide the most sensitive and earliest indicators of chemical exposure and effect.

Application of this idea requires additional research on the molecular mechanisms of chemical toxicity in aquatic organisms and intelligent adaptation of existing mammalian diagnostic tools. Since relevance of biochemical responses to populatons and ecosystems is not always obvious, there is an even greater need for landmark studies that link chemical exposure to responses of individuals, populations and ecosystems. Such "calibrations" will reduce the need for expensive and time-consuming studies of ecosystems and will increase the acceptability of biochemical techniques. The may also help us recognize patterns of population response unique to chemical stresses.

Introduction

Monitoring is an integral part of environmental management. The products of monitoring are data bases that demonstrate spatial and temporal trends in specific environmental characteristics. These trends help to identify sources and specific impacts of stresses, to provide early warning of developing problems, and to demonstrate the success of remedial actions. Monitoring strongly affects expenditures on pollution control, the activity of resource industries and the effort devoted to resource management.

Monitoring can describe the extent, nature and effects of stresses on aquatic ecosystems. For toxic substances, chemical monitoring describes the levels of specific chemicals in various media, usually in relation to fixed criteria (e.g. guidelines for chemical contamination of edible fish products). By itself, chemical monitoring describes possible causes of environmental problems without measuring associated effects. Meeting water quality objectives provides no assurance that aquatic biota are protected from the effects of unexpected chemicals, of chemical mixtures and of the interactions between chemical exposure and environmental stress.

Biological monitoring measures the status of aquatic biota by examining communities, populations and individual aquatic organisms. The "health" of an aquatic ecosystem is described in terms of the structure or performance of aquatic communities relative to bench marks based on history, related ecosystems or theoretical calculations. Aquatic biota integrate spatial and temporal variations in exposure to single and combined stresses. However, by integrating many stresses, aquatic biota can only demonstrate effects without defining causes. Clearly, biological and chemical monitoring must be combined for effective management of chemical problems. This paper describes two approaches to monitoring chemical effects on single species, with an emphasis on fish.

Biological Monitoring of Species

The purpose of monitoring is to provide information that can be used to protect beneficial uses of water. A fundamental flaw of biological monitoring is that the system we wish to protect is the indicator of chemical effects. Therefore, to prevent major losses of fisheries, monitoring must measure biological responses with the following properties (Hodson 1986):

a. They "must have an early warning capacity, occurring well in advance of a loss of beneficial uses and at or below the threshold of exposure causing such a loss";

b. they "should be specific to an individual chemical or group of chemicals" and insensitive to other confounding factors such as fishing pressure, the effects of spawning, etc."; and

c. they "should be related to exposure and to other significant chemical effects by strong dose-response relationships."

The "health" of an ecosystem can be assessed by monitoring a species in two ways: a "top down" or holistic approach and a "bottom-up" or reductionist approach.

The "top down", or holistic approach treats a species as a "bellwether". Adverse responses are noted by monitoring and the causes sought - we observe effects for which causes are not immediately obvious (e.g. tumours in Great Lakes fish). Ryder and Edwards (1985) have proposed various criteria for species that could act as an "ecosystem indicator" (Table 1). As an example, they provided a rationale for using the lake trout as an indicator of the quality of cold-water, oligotrophic conditions in the Great Lakes. Lake trout have very specific environmental requirements that correspond to those of oligotrophic ecosystems and are top predators in such ecosystems. Therefore, the mere presence of naturally-reproducing, self-sustaining populations with a productivity similar to that of historic norms is evidence of a high quality ecosystem. If the lake trout are edible and can sustain a commercial or sport fishery, objectives for managing environmental quality have been met.

Therefore, the lake trout is a surrogate for other measures of environmental quality.

Table 1 **Criteria for an ecosystem indicator** (from Ryder and Edwards, 1985)

- have a broad distribution in the environment
- be easily collected and measured in terms of biomass
- be indigenous and maintain itself through natural reproduction
- interact directly with many components of the ecosystem
- have historical, preferably quantified, information pertaining to its abundance and other ciritical factors relevant to the state of the organism
- have well-documented and quantified niche dimensions expressed in terms of metabolic and behavioural responses
- exhibit a gradual response to a variety of human-induced stresses
- be a suitable species for laboratory investigations
- be generally recognized as important to humans
- serve to indicate aspects of ecosystem quality other than those represented by presently accepted parameters.

Monitoring to meet the "lake trout objective" would include the traditional measures of population status employed by fisheries biologists plus chemical monitoring of edible portions.

The advantages of this approach are several:

- integration - populations of the structure and productivity of all trophic levels beneath. Hence, any factor that has a significant effect on any trophic level will affect the top predator;
- relevance - effects on top predators, particularly species of commercial importance, will general public support for remedial actions. From an ecological perspecive, only "important" causes and effects will be observed. For example, minor changes in algal productivity, while a real effect of toxic chemicals, might not be corrected if there were no subsequent changes in lake

trout productivity;

- perspective - historical data sets on commercial and sports fisheries provide bench marks against which to compare current conditions;
- standard methods - for commercial fish species, the methods of monitoring and analyzing data are well established;
- application - while lake trout are found in a restricted set of conditions, the concept of a species objective is widely applicable. Presumably, suitable species can be found to represent environmental quality in any ecosystem, although well-studied commercial species may not be present in every system;
- quantitative - data describing the health of fish populations are usually described statistically;
- scientifically defensible - the environmental requirements of many species are well understood and there is a strong relationship between environmental quality and fisheries productivity;
- catch-all - chemical monitoring is primarily concerned with well-known problems. For unknown or unexpected chemicals (e.g. PCB's before the 1970's), monitoring the population of an integrator species should demonstrate the effect of their presence;

The disadvantages of this approach are:

- no early warning - the most important response to a stress, declining productivity of a population, identifies a problem and is the starting point in finding the cause. If the cause is slow to develop and cumulative (e.g. the build up of persisent chemicals in ecosystems), the diagnosis of cause may be too late to save the population or to prevent disruption of fisheries;
- poor specificity - Declining fish productivity is a very general response to many stresses. For environmental management, the diagnostic potential is poor;

- dose response relationships are obscure - large scale changes in ecosystem structure and function may be necessary before a top predator responds. Rather than responding in a graded fashion with exposure, populations of predators may decline suddenly as a threshold of environmental change is exceeded. Given the inherent variability in population structure and productivity, important changes may also not be obvious until damage is severe.

Colby (1984) has proposed that the patterns of change for a variety of population characteristics (e.g. size at age, age at maturity, fecundity, mean size, etc.) could be used to diagnose specific stresses. These patterns might also help to identify the critical life stage affected. While there are specific patterns typical of fishing pressure, there have been no studies of changes related to chemical contamination.

Research Needs.

1. Case histories - Research is needed to demonstrate how fish populations respond to either direct effecs of chemical exposure or to effects on lower trophic levels. Are responses graded or sudden after stress thresholds are exceeded? The hypothesis put forward by Colby (1984), that there are patterns of response due to chemical toxicity, should be assessed in contaminated ecosystems.
2. Environmental requirements of aquatic biota - the specific habitat requirements of non-commercial species need to be described, particularly in ecosystems where commercial species are absent.
3. Characteristics of populations - indicator species are currently restricted to those that have been monitored in support of commercial fisheries. For other species, little data exists on normal population structure and productivity, even though they may be appropriate monitoring species.

One solution to these problems is the "bottom-up" or reductionist approach using the responses of individual organisms within a species to asses ecosystem health. Measurements are usually of biochemical, physiological, pathological, or morphological changes that can be related to chemical residues in tissues.

The basic assumption of this approach is that all chemical effects on populations and ecosystems begin with chemical accumulation by individual organisms and with a reaction between the chemical and some biological substrate (Hodson 1986). Since these responses are often very specific for one chemical or group of chemicals, several responses may form a diagnostic pattern. The most specific tests will be of the actual biochemical reactions of toxic chemicals (e.g. inhibition of specific enzymes). Less specific, but equally useful measurements would be the secondary or tertiary biochemical and physiological responses arising from the initial reaction (e.g. the increased activity of the mixed function oxidase system in response to induction of enzyme synthesis caused by exposure to polynuclear aromatic hydrocarbons).

These diagnostic tests indicate that organisms are both exposed to chemicals and have responded to that exposure. Measures of the individual's exposure and response can answer questions about the bioavailability of contaminants and can provide potential mechanisms to explain effects at higher levels of organization. For example, biochemical and physiological changes can be translated into effects on the growth, reproduction and mortality of the individual and may provide a starting point for models of population responses. This idea is presented conceptually in Figure 1.

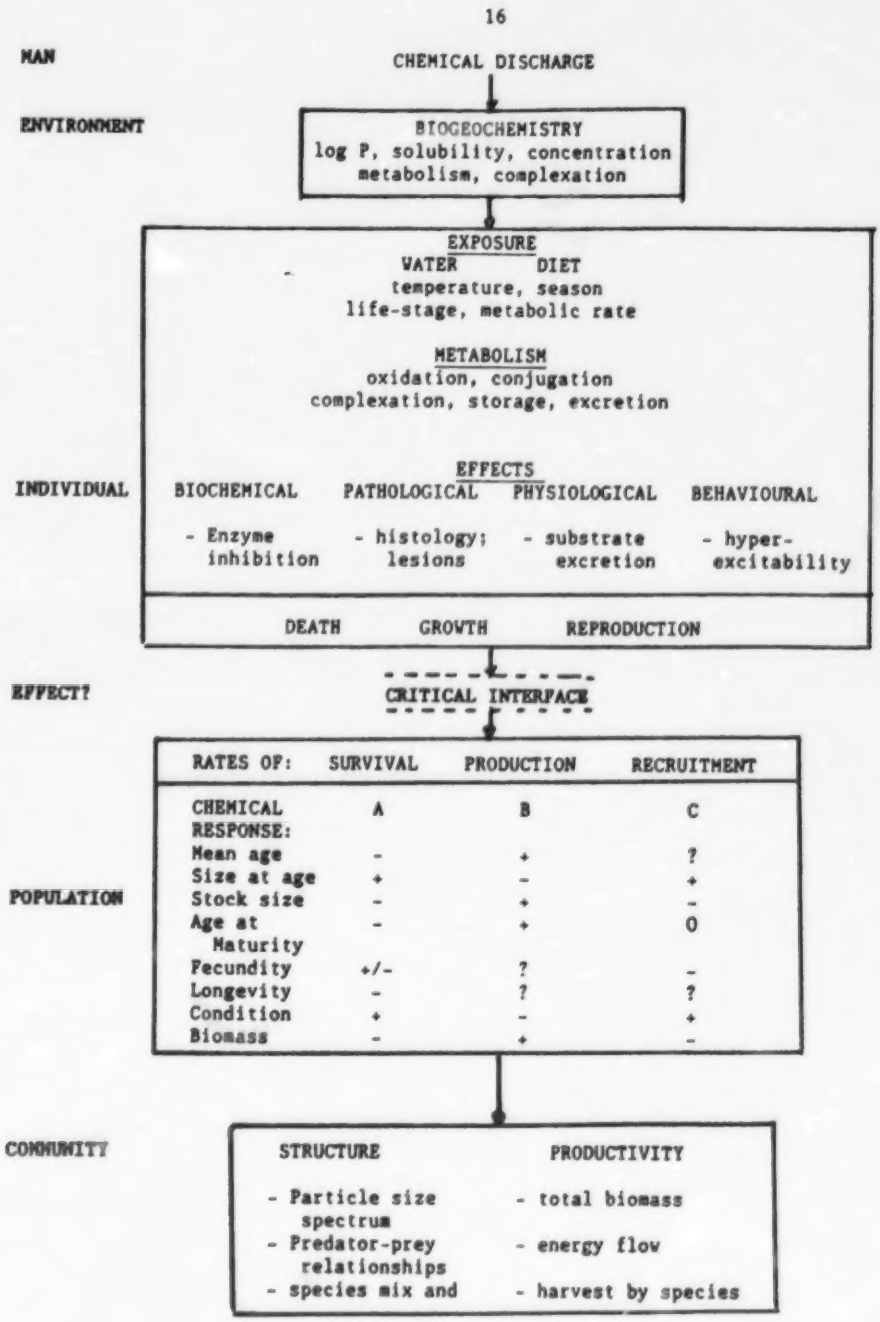


Figure 1

Hypothetical chain of events following release of chemicals to an aquatic ecosystem. Only a small number of factors affecting chemical fate and effect and a small number of responses are shown.

The advantages of clinical tests are:

- early warning - the measurement of the first chemical reactions due to the accumulation of toxic chemicals by fish is an indication of potential damage to populations. Biochemical and physiological responses occur at far lower levels of chemical exposure than do population responses;
- specific - since chemical reactions have specific and rigorous requirements, they provide highly specific measures of the presence and effects of single chemicals or groups of chemicals. This means a rapid diagnosis of cause and appropriate remedial actions;
- dose-response - the strength of biochemical responses is usually directly proportional to the amount of chemical present;
- broad applicability - the reactions between chemicals and biological substrates are often found in most organisms. Variations between species are often a function of differences in accumulation rates rather than of differences in toxic mechanisms;
- scientifically defensible - diagnoses are based on known mechanisms of toxic action;
- quantitative - results are usually expressed in statistical terms.

The disadvantages of this approach are:

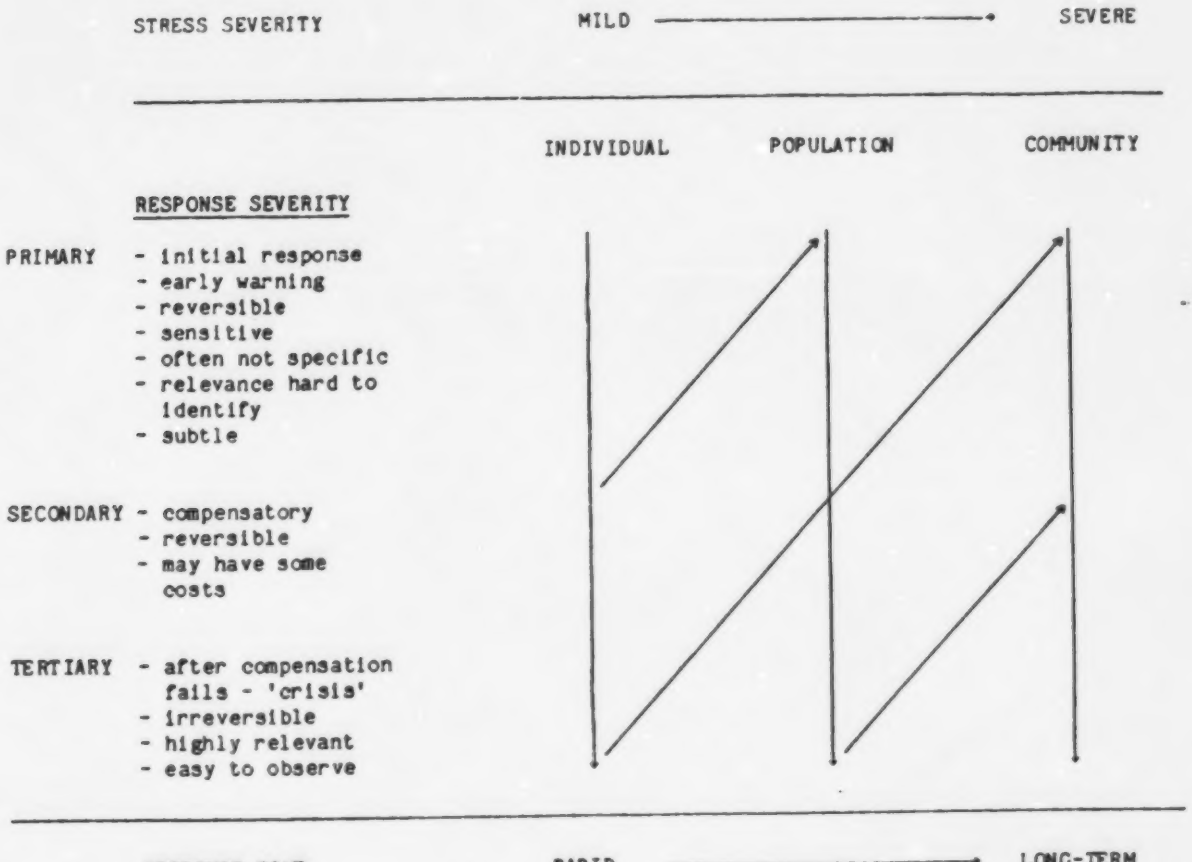
- relevance - the ecological significance of biochemical changes in individuals is not immediately obvious to either environmental managers or to ecologists Chemically-induced changes in individuals are similar to other natural diseases and all populations can compensate for natural rates of disease. Furthermore, the responses of populations are unlike those of individuals - populations possess unique characteristics. Biochemical changes indicate an increased probability of population effects but the link to population effects has not been well described experimentally (see "critical interface" of

Figure 1). The conceptual link between biochemical changes and effects on populations is summarized briefly in Figure 2 from Dixon et al. (1985).

- lack of tools - There are few good studies of the mode of toxicity of chemicals in aquatic organisms. Consequently the development of clinical diagnostic tools is limited to those or which a mode of toxicity is well defined in mammals. The application of these tools to aquatic species is not always simple but can be resolved (see Dixon et al. 1985). The lack of tools means that many chemicals may occur in fish but few can be evaluated for effects.
- perspective - since most diagnostic tools are relatively new, there are no historical data sets to provide perspective on current conditions. "Normal" values must be used on studies of uncontaminated controls.

Research Needs.

1. Studies are needed in aquatic biota of the molecular mode of toxic action of the more common classes of polluting chemicals. Understanding mechanisms will lead to specific diagnostic tools.
2. Routine monitoring - existing tools should be added to biological monitoring programs to provide historical records and definitions of "normal".
3. Case studies need to demonstrate the relationship between chemical exposure of fish, early biochemical and physiological responses, and ultimate effects on populations and ecosystems. Such studies will indicate the significance of biochemical changes and the degree of exposure needed to trigger remedial actions. A few "land mark" studies will calibrate the biochemical approach, reduce the need for expensive ecological studies and increase the acceptability of biochemical monitoring.



- A primary response at the individual level will cause few, if any, changes at the population and community level.
- A secondary response at the individual level will have some energy cost (e.g. reduced growth rate) which may cause some primary changes in population structure.
- A tertiary response at the individual level (e.g. high mortality of a specific age class) may cause significant changes in population structure leading to compensation (e.g. changes in fecundity) and some early changes in community structure (e.g. changes in predator-prey relationship).
- A tertiary change in population structure (e.g. extinction of a species) may cause secondary or compensatory community changes (e.g. change in species dominance).
- A tertiary change in community structure would represent loss of species and be equivalent to a complete degradation of the environment (e.g. oligochaete-dominated benthos near sources of organic pollution).

Figure 2

Stress response matrix showing the conceptual link between effects on individuals and effects on populations and ecosystems. Taken from Dixon et al. (1985).

Selenium as an Example

Selenium is an element normally found at low levels in aquatic ecosystems. Concentrations in the Great Lakes, for example, are generally less than 0.1 ug/L in water and 1.0 ug/g dry weight in sediment (Hodson et al. 1984). Biota also contain little selenium; whole fish from various parts of the Great Lakes contained 0.1 to 1.55 ug/g wet weight, with most samples having less than 1.0 ug/g. Net plankton and benthic invertebrates contained 0.8 - 4.70 ug/g dry weight (roughly 0.16 - 0.92 ug/g wet weight) (Hodson et al. 1984).

Since these values are typical of most surface waters, it was somewhat surprising that the disappearance of fish from Belews Lake, a thermal power reservoir in North Carolina, was associated with elevated levels of selenium in water (Cumbie 1978; Cumbie and Van Horn 1978). Lower standing stocks and reproductive failure could not be linked to pesticides, water levels, temperature, impingement and entrainment, diseases or parasites, and the loss of fish was not observed in more remote parts of the same reservoir.

The reservoir served a power plant that was coal fired; the coal contained 5.2 ug/g of selenium and its fly as 17.3 ug/g. Effluent from the fly ash settling pond contained 150-200 ug Se/L while lake water had 5 - 10 ug/l with occasional peaks to 20 ug/L. Compared to control sites, selenium levels were higher in fish (10 - 50 vs 0.5 - 7 mg/kg), plankton (40 - 100 vs 4 - 20 mg/kg dry weight), and sediments (6 - 8 vs 3.4 mg/kg dry weight). While arsenic was also elevated in effluents and sediments, it was not elevated in biota (Cumbie, 1978; Cumbie and Van Horn 1978). Selenium contaminated fish showed all the signs of selenosis (Table 2) and surviving centrarchids exhibited both reproductive failure and high levels of selenium in ovaries of females.

Table 2 **Symptoms of acute selenosis in freshwater fish**

Dysfunction	Symptoms	References
1. Loss of osmotic control	- exophthalmous ("popeye") - distended abdomen - peritoneal fluid (ascites) - loss of equilibrium - increased condition factor - reduced hematocrit	Ellis 1937 Sorensen et al. 1984
2. Histophathology	- gills - swollen lamellae, cellular vacuolation - ovary - necrotic and degenerating follicles - liver - vacuolation of parenchymal hepatocytes; increased number of Kuppfer cells - kidney - proliferative glomerulonephritis - heart - pericarditis, myocarditis due to uremia arising from kidney damage - erythocytes - distorted red cells	Sorensen et al. 1984 Finley 1985
3. Liver damage	- increased liver somatic index	Sorensen et al. 1984

These results were paradoxical: the literature values for acute selenium lethality to fish (600 to 35,000 ug/L; Hodson et al. 1984) were far higher than the observed levels of selenium in water (< 20 ug/L). Chronic toxicity was also typical of higher levels of selenium: laboratory tests with trout demonstrated elevated rates of mortality and deformities at concentrations in excess of 60 ug/L and only subtle haematological effects at levels as low as 28 ug/L (Hodson et al. 1984). Therefore, it seemed unlikely that waterborne selenium could cause acute toxicity to fish in the reservoir, although it is conceivable that waterborne selenium levels might increase periodically to higher levels.

Based on the strong association between selenium and fish disappearance, the ash pond effluent was further treated and selenium levels in Belews Lake reduced to 5 ug/L. However, stocking of the reservoir with large mouth bass

fingerlings (Micropterus salmoides) resulted in the total loss of the stocked fish (Cumbie 1980).

Since selenium levels in the water were low while plankton levels were high, there was a possibility of a dietary source of toxicity. Studies by Goettl and Davies (1978), confirmed by Hilton et al. (1980), showed that dietary selenium was highly toxic to trout. Levels of 10 - 13 mg/kg of dietary selenium were sufficient to cause elevated mortality rates, reduced growth rates and obvious signs of selenosis. Since only small elevations of selenium in prey items by 10 - 20 times normal background levels might cause mortality, it was possible that food-chain accumulation of selenium caused the disappearance of fish.

This hypothesis was confirmed by analysis of benthic invertebrates (70 vs 4 - 8 ug/g dry weight at control sites; Cumbie 1980) and by an experiment in which bluegills (Lepomis macrochirus) were stocked into fenced off portions of the affected and control areas. All fish died in the affected area within 10 - 14 days. In a second trial, some fish were allowed to roam freely within the fenced off portions of the study areas while the remainder were confined to cages isolated from the bottom. Those fish with access to bottom sediments died rapidly in affected areas but not in control areas; fish in the cages survived over the short-term. All dying fish had benthic invertebrates in their stomachs and signs of selenosis. Caged fish in the affected area gradually died over the summer, usually after consuming emerging insects. Selenium analyses demontrated highest levels in fish roaming freely in treated areas, intermediate levels in caged fish from treated areas and lowest levels in all control fish. These data were interpreted as dietary toxicity due to the consumption of highly contaminated benthic invertebrates, either in the larval stage or as emerging adults. Benthic feeding fish were estimated to accumulate a lethal dose within 1 to 3 days (Cumbie 1980).

The hypothesis of dietary toxicity was further confirmed by feeding Hexagenia limbata larvae from Belews Lake sediments to four bluegills in the laboratory. Compared to four controls fed clean mealworms (Tenebrio molitor), the treated group accumulated high levels of selenium, developed symptoms of selenosis, and three of four test fish died (Finley 1985).

Centrarchids were among the fish species most sensitive to selenium, and were usually the first to disappear from contaminated lakes. Surviving female fish had very high concentations of selenium in the ovaries. Experiments with sexually mature male and female fish demonstrated that ovarian selenium was the cause of reproductive failure in these fish. Gametes from both clean and contaminated fish were crossed and offspring from contaminated females developed edema and died as larvae; the selenium levels of males had no effect on survival (Gillespie and Baumann 1986).

The links between waterborne selenium and dietary toxicity included both changes in the state of selenium in aquatic environments and differences in the metabolism of dietary and waterborne selenium by fish. The majority of selenium in Belews Lake was soluble, passing through a 0.45 u filter (Cumbie 1980). Selenium has a half-life of about 25 - 50 days in water unless it is in contact with the sediments when it is rapidly adsorbed by sediments (Rudd et al. 1980).

Since sediment bacteria can methylate selenium to a volatile form or reduce it to elemental selenium (Chau et al. 1976; Silverbert et al. 1976), it is possible that invertebrates may contain a form different than found in water. Kleinow and Brooks (1986) found that gastric absorption of selenomethionine by fathead minnows (Pimephales promelas) was faster than either absorption of selenite or selenate. Therefore, the form of selenium may affect both dose rate and toxicity. The form taken up by aquatic invertebrates and ingested by fish is currently unknown, but dietary selenite appears to be metabolized very

differently from waterborne selenite (Hodson and Hilton 1980). The accumulation and loss of waterborne selenium follows a passive diffusion model, while active excretory processes are typical of dietary selenium. Since these excretory processes appear to be mediated by the liver, and since they can be overwhelmed by high dietary loading, accumulation and toxicity of dietary selenium can be readily induced and is indicated by high levels of selenium in liver and kidney.

These observations on selenium toxicity are not unique. Agricultural drainage in the San Joaquin Valley of California has leached selenium from the soils and caused contamination of aquatic food chains. The result has been fish kills and, possibly, mortality and deformities in chicks of fish-eating birds (Saiki 1986; Ohlendorf et al. 1986).

Biomonitoring played a very strong role in solving this environmental problem. Population monitoring provided the first indications of a problem but the only clue about possible causes was the distribution of affected populations. Monitoring chemical levels and pathology in individual organisms was required for rapid identification of selenium contamination as the most likely cause. Despite paradoxically low levels of selenium exposure, the responses of individual fish so strongly suggested selenium poisoning that food chain accumulaton of selenium was investigated as an exposure route. The ultimate demonstration that food chain accumulation of selenium can cause toxicity to top predators in aquatic food chains is remarkable for the fact that this is one of the few cases in which an element is biomagnified sufficiently to cause toxicity in feral organisms. The only other case is that of elemental phosphorous which poisoned marine food chains in Placentia Bay in 1969 (Jangaard 1972). In both cases, field observations of dying fish gave notice of a problem and symptoms in individual fish provided the diagnosis based on laboratory tests of toxicity.

Conclusions

1. Traditional water quality monitoring is an inadequate way to monitor the health of aquatic ecosystems. Even when all water quality objectives have been met, biogeochemical processes such as methylation and biomagnification can enhance accumulation and toxicity of chemicals. In the selenium example, water quality monitoring indicated that, while selenium was enriched, the levels in water were below those causing harm to fish.
2. Fish population monitoring provides an important, highly relevant first indication of impaired environmental quality, but is a poor basis for diagnosing cause. the disappearance of fish and chemical analyses of water were inadequate to identify selenium as the cause in the above example.
3. The response to chemicals of individual organisms (biochemical, physiological, pathological changes), when coupled with chemical measurements, provides an excellent basis for diagnosing chemical exposure and effects. The consistent association of signs of selenosis with elevated environmental and tissue residues produced the diagnosis of selenium as a cause of disappearing fish in Belews Lake.
4. There is a critical interface between responses to chemicals of individuals and responses of populations. While chemical effects on individuals are well-studied and understood, our ability to understand and predict effects on populations is very poor. There are few studies linking responses of individuals and of populations to chemical exposure.
5. The most efficient monitoring programs will integrate the measurement of chemical levels in fish and other environmental samples with measurements of the health of fish populations and symptoms of chemical effects in individual organisms.

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WATER QUALITY INDICES AS INDICATORS OF ECOSYSTEM CHANGE, Margaret House, Middlesex Polytechnic, Queensway, Enfield, EN3 4SF. England, U.K.

Introduction

Changes in river water chemistry can be the result of domestic, industrial or agricultural discharges which may in turn lead to ecosystem dysfunctions. Therefore, chemical parameters can act as indicators of pollutant leakages within natural and/or manmade drainage systems. In addition, accumulations and/or fluctuations of parameter concentrations can serve to highlight potential ecosystem dysfunctions and thereby provide an early warning of possible ecological problems. The potential list of physio-chemical parameters that could be monitored to indicate such dysfunctions is very considerable. Even if they could all be monitored, there would be insufficient time available to water quality managers to analyze the vast amounts of data that would be produced. This dilemma often results in Water Authorities monitoring some forty parameters but with detailed data analysis concentrating on only three or four key parameters (House, 1986). Consequently, what is needed is a more effective method of communicating information on a range of physio-chemical parameters in terms of their chemical and ecological significance. A number of approaches to this problem have been attempted which range from the use of subjectively applied water quality classifications, to the development of mathematically derived water quality indices (WQI's). The purpose of this paper is to discuss the development and use of WQI's in the operational management of surface water quality and to highlight the value of such an approach as a potential indicator of ecological change.

Background to the use and development of Water Quality Indices

A water quality index allows the reduction of vast amounts of data on a range of physio-chemical and biological parameters to a single number in a

simple and reproducible manner. They are mathematically derived and threfore allow the objective assessment of water quality and permit meaningful spatial and temporal comparisons to be made. Therefore WQI's, based upon those parameters considered to be most indicative of water quality and ecological change, can be used to summarize vast quantities of data to a single number. This allows the quantification of "good" and "bad" water quality, the summation of parameter effects and an indication of river reaches which have changed significantly in quality, and which, if necessary can be investigated in greater detail. Therefore, WQI's not only act as indicators of ecosystem change, but can also indicate the effect these changes may have on the use of water or the ability of water to support healthy fish and wildlife populations. In addition, the application of indices to a variety of locations can allow the cause of such changes to be detected. Finally, an index suited to computerization thus reducing the amount of time involved in classifying surface water quality.

There are four stages in the development of a water quality index:

1. parameter selection;
2. the transformation of parameters to the same scale;
3. the development of parameter weightings; and
4. the selection of an appropriate aggregation function.

Previous research has resulted in the development of four separate indices (House, 1986). These may be used either independently or in combination with one another where a complete assessment of water quality is required. The first of these is a General Water Quality Index (WQI) which reflects water quality in terms of a range of potential water uses (Table 1). This index is based upon nine physio-chemical and biological parameters which are routinely monitored by the Water Authorities and River Purification Boards of the U.K., and relates water quality to a 10 to 100 index scale. The second, the Potable Water Supply Index (PWSI) is based upon thirteen routinely monitored parameters, but reflects water quality exclusively in terms of its suitability for use in potable water

Table 1. Sub-Divisions of the 10 - 100 Water Quality Index Scale

Use Score	PWS	FAWL*	Industry	Recreation	Sewage Transport And Navigation
100	No treatment required		Selected uses without treatment		
90		Suitable for all species of fish and wildlife	Minor purification if high quality water required	Suitable for all recreational activities	Possible Restriction
80	Minor Purification				
70		Doubtful for game fish	No treatment for most uses	Doubtful for direct contact sports	Completely Acceptable
60	Conventional treatment	Supports good populations of coarse fish			
50	Advanced treatment	Reasonable coarse fisheries	Advanced treatment required for most uses	Indirect and non-contact activities only	
40	Doubtful use	Tolerant species only			
30			Only industries needing poor quality water	Non-contact uses only	
20	Unacceptable	Unacceptable	Unacceptable	Unacceptable	
10					

From House and Ellis (1986)

N.B. * Fish and Wildlife

supply (PWS). The scale for this index was lowered to zero due to the potential risks to human health. The two remaining indices, the Aquatic Toxicity (ATI) and Potable Sapidity (PSI) Indices are based upon toxic determinands such as heavy metals, pesticides and hydrocarbons which are potentially harmful to both human and aquatic life. Both indices are use-related, the former reflecting the suitability of water for the protection of fish and wildlife populations, whilst the latter reflects the suitability of water for use in PWS. Each index is based upon nine and twelve toxic parameters respectively and relate water quality to a zero to 10 index scale. The parameters included within these indices are listed in Table 2.

Table 2 **The Parameters Included Within the Four Independent Indices**

WQI	ATI	PSI
Dissolved Oxygen	Dissolved Copper	Total Copper
Ammoniacal Nitrogen	Total Zinc	Total Zinc
Biochemical Oxygen Demand	Dissolved Cadmium	Total Cadmium
Suspended Solids	Dissolved Lead	Total Lead
Nitrates	Dissolved Chromium	Total Chromium
pH	Total Arsenic	Total Arsenic
Temperature	Total Mercury	Total Mercury
Chlorides	Total Cyanide	Total Cyanide
Total Coliforms	Phenols	Phenols
		Total Hydrocarbons
		PAH's
		Total Pesticides

PWSI
The WQI Plus
Sulphates
Fluorides
Colour
Dissolved Iron

Rating curves were selected as the best way in which individual parameter concentrations could be transformed to the same scale. The curves were developed using published water quality standards and guidelines relating to specific water uses. Therefore, they contain information on standards which must be adhered to within the

European Community and this adds a further dimension to their management flexibility. Weightings indicating the empahsis placed by water quality experts upon individual parameters were assigned to the parameters of the WQI and PWSI. However, weightings were omitted from the ATI and PSI due to the sporadic nature of pollution events associated with these parameters. These vary spatially and temporally, both in concentration and in terms of those parameters which violate consent conditions. Therefore, on a national scale, no one parameter could be isolated as being more important than any other. Finally a modified arithmetic formulation was selected as the most appropriate form of aggregation function.

Of these four developmental stages, parameter selection and rating curve development are undoubtedly the most important. To be of value as either indicators of water quality or ecological change and dysfunction it is essential to include those parameters which are the best indicators of both ecosystem change and dysfunction. Once selected, parameters must be transformed to the same scale in a meaningful fashion, relating water quality to potential use using recognized standards and criteria. A more detailed account of the development of these indices can be obtained from House (1986).

Indices as Indicators of Ecological Change

These indices have been primarily developed to reflect changes in the physio-chemical quality of surface waters. However, they may be used as indicators of ecological change. Temporal variations is occurring within an aquatic system. By relating water quality to potential water use, the effect of this change on the system may be recorded. For example, if water quality was to change from a score of 55 to 40 the survival of healthy coarse fish populations would become doubtful (Table 1). Conversely, an improvement from 55 to 70 would indicate potential for the introduction of salmonid species. However, it must be stressed that the value of index scores as indicators of ecological change is determined by the value of

the data upon which they are based, and hence upon both the index design and monitoring procedures.

The Application of Indices to Water Quality Management

The WQI has been applied to data collected by the Severn Trent Water Authority (STWA) for the fiscal years 1978/1979 and 1979/1980 (STWA, 1980). The initial aim of this investigation was to compare the value of information derived using this index to that produced by the application of the National Water Council Classification (NWC, 1977), the technique presently employed by the UK water industry. The "adequacy and sensitivity" of this classification has been subject to considerable criticism over the last twelve months which is highlighted in a recent report produced by the House of Commons Environment Committee (HMSO, 1987).

The results of the initial investigation showed that the WQI similarly classified 132 of the 136 data sets with index scores of 24 to 92 being recorded. These results validate the ability of the index to detect fluctuations in surface water quality. In addition, the study highlighted a number of advantages of using an index over the NWC Classification (House, 1986). The data was next classified according to the WQI classification (Table 3). The results from this classification were then compared to the calculated index scores to highlight the value of information derived from a refined water quality scale over that of any classificatory system. A sample of these results is shown in Table 4.

Table 3 **The WQI Classification**

Class	Index Score	Interpretation
1	71-100	Indicates water of high quality suitable for all high value uses at low cost.
2	51-70	Indicates water of reasonable quality suitable for high value uses at moderate cost.
3	31-50	Indicates polluted water with generally moderate value uses and high treatment costs.
4	10-30	Indicates badly polluted waters of low economic value requiring large investment in treatment facilities if they are to be upgraded.

Table 4. Results From the Analysis of Severn Trent Water Authority Data Using The WQI

Location	1978/1979 WQI Class	1978/1979 WQI Score	1979/1980 WQI Class	1979/1980 WQI Score
River Clywedog	1	92	1	78
River Vyrnwy	1	82	1	81
Rea Brook	1	77	1	74
River Roden	2	65	3	47
River Worfe	2	70	2	52
River Onny	1	74	2	69
River Corve	1	74	2	61
River Isbourne	2	70	2	65
Bow Brook	2	68	2	65
River Leadon	2	67	2	63
River Frome	2	69	2	69
River Trent				
- Hanford	3	43	3	42
- Stone	3	39	3	49
- Great Haywood	2	52	3	47
- Yoxall	2	56	2	58
- Walton	3	39	3	42
- Willington	3	47	3	50
- Shardlow	2	53	2	56
- Sawley	2	57	2	59
- Nottingham	2	53	2	55
- Kelham	2	51	2	53
- Dunham	2	56	2	56
- Fowlea Brook	3	33	3	34
River Blithe	1	71	2	69
River Rea	3	44	4	29
River Anker				
- Leathermill Bdg	3	45	2	56
- Polesworth	3	45	3	50
- Ratcliffe Culey	2	58	2	67
River Dove				
- Below Rocester	1	73	1	82
- Monks Bridge	2	70	1	74
River Churnet				
- Abbey Gn. Rd.	2	64	2	52
- Rocester	2	62	2	62
River Tean	3	42	2	61
River Derwent				
- Matlock Bath	1	76	1	84
- St Mary's Bdge	1	72	1	77
- Wilne	2	61	2	67
River Amber	3	48	2	51
Alfreton Brook	3	36	3	39
River Erewash				
- Trowell	3	36	3	34
- Confluence	3	31	4	30
River Leen	3	42	2	52
River Idle/Maun				
- Whinney Hill	4	27	4	24
- Bawtry	2	55	2	62

The results showed that over half of the data sets (74) fall into Class 2 indicating waters of moderate to high value capable of supporting good coarse fisheries and suitable for use in potable water supply after conventional treatment as defined by the EEC (1975). Only 14 of the river reaches recorded index scores of below 30 indicating badly polluted waters. Of greater interest and importance is the analysis of trends in surface water quality for the two year period. Of the 68 river reaches for which data were available, five appear to have been upgraded and seven downgraded by one class. However, when these results are examined more closely using the actual index scores it is apparent that of these twelve river reaches, five already indicated borderline water quality classifications with actual index scores recorded changing by only 1 to 5 points on the 10 to 20 index scale. This highlights the danger of using any classificatory system in isolation of more specific information. The upgrading of the River Dove at Monks Bridge and the River Amber, although important, are not as significant as their classifications would suggest (Table 4). Similarly, the dowgrading of the River Erewash was in fact the result of a one point change on the index scale, and is therefore of negligible importance. Hence, the use of a numeric scale allows the precise location of a water body within a class to be determined. This is critical when ambient water quality approaches class threshold values. However, both the classification and numeric scale allows the clear definition of between class variations in surface water quality to be recorded.

A further analysis of the data in Table 4 highlights the way in which an index may be used to pin-point river reaches which have altered in quality over the two year period. For example, the rivers Clywedog, Worfe, Trent at Stone and the Churnet at Abbey Green Road all remained in the same class over the two year period. However, the actual quality in the same class decreased or increased by between 10 to 18 points on the 10 to 100 index scale. The greatest

change in water quality from 70 to 52. These scores represent both extremes of the Class 2 index range. The former indicates water of borderline quality for the introduction of salmonid species and the potential for use in direct contact recreation activities. The latter indicates water which can support only moderate coarse fish populations with use further limited to non-contact water sports and recreation activities. The drop in quality recorded for the River Clywedog, although less dramatic, is extremely important as quality has changed from a high Class 1 of 92 to 78 in a single year. This indicates a substantial change in chemical water quality which may in turn act as an indicator of potential ecological damage, providing an early warning system for the water resources manager.

Similar "within class" variations can be noted for other rivers, each indicating the need for a precise form of water quality reporting system. Without such a system it is possible that many of these temporal variations in water quality may go undetected.

The interpretation of spatial variations in surface water quality is similarly hampered when using a classificatory system in isolation. For example, the River Trent at Willington and the River Erewash are both classified as Class 3. However, they have index scores which locate them at opposite ends of the Class quality spectrum (50 and 31 respectively). The ecological significance of such a variation in quality at this end of the water quality scale may be substantial (Table 1).

The discussion in this instance has centred upon a comparison between two forms of the same analytical and reporting tool; the index classification versus the numeric scale. There is no reason why the former may not be used in isolation for the reporting of water quality at the directorate level or to the public. However, operational catchment management requires the precision and

unambiguous qualities that can only be provided by the use of the numeric scale. When comparing the results produced by the WQI with those of the NWC Classification the differences were considerably more dramatic and substantial casting doubt on the value of the classificaiton as a whole (House, 1986; House and Ellis, 1986).

Conclusions

The specific advantages of WQI as an indicator of ecological change may be summarized as follows:

a. it enables large amounts of water quality data to be reduced to a single index value in an objective, rapid and reproducible manner;

b. because of the numeric scale, an index can provide information on "within class" variations in quality which are of particular importance where class or use threshold values are approached. In this way an index can be used to pin-point reaches, on a spatial and temporal basis, which have altered significantly in quality, but insufficiently to merit a change of class within a classificatory system.

c. In addition, index scores are unambiguous, precisely indicating quality, rather than the close approximation provided by a classificatory system. This is of considerable importance because the final classification produced by a water quality monitoring system may be used in the development of river quality objectives. If these are to be realistic and meaningful, they must be based on an accurate assessment of current water quality.

d. An index may be used to assess the ecological potential of a water body through a consideration of the potential water use associated with its index score. Similarly, a change in the ecological potential of a water body can be inferred from an increase or decrease in the index score.

e. As this index has been developed in accordance with recognized, and often legally accepted, water quality standards and criteria, it may be used by operational management to identify surface waters requiring priority action.

f. An index may also be used at the directorate level or for the provision of information to the layman in simple, but precise terms by dividing the index scores into broader classes, while at the same time maintaining the initial precision.

Thus this index, and other indices developed as part of this research, provide a precise picture of water quality, provide additional management, flexibility and facilitate the development of best management practices.

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MONITORING THE CONDITION OF THE CANADIAN FOREST ENVIRONMENT: THE RELEVANCE OF THE CONCEPT OF "ECOLOGICAL INDICATORS"

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Abstract

The Canadian forest environment is characterized by high spatial (especially in the west) and temporal variability. Our forests vary according to climate, landform, and surficial geology, and according to the type, intensity and extent of, and the time since the last disturbance. Most Canadian forests have had a history of repeated acute, episodic disturbance from fire, insects, wind, diseases and logging, with a frequency of disturbance varying from a few decades to many centuries. These sources of variability have resulted in a complex mosaic of forest conditions and stages of successional development.

Monitoring the "quality" of this landscape mosaic is extremely difficult, and in most cases the concept of a relatively simple index of forest ecosystem quality/condition (i.e. an "ecological indicator") is probably inappropriate. Ecological indicators are probably better suited for monitoring chronic disturbances that are continuous in their effect, such as "acid rain", heavy metal pollution, air pollution, and the "greenhouse effect". Monitoring the effects of the acute, episodic disturbances that characterize forests will require the definition of the characteristic

pattern of disturbance and recovery therefrom (i.e. patterns of secondary succession). The somewhat overwhelming complexity of this task has led forest ecologists to the use of ecosystem-level computer simulation models.

Appropriately structured and calibrated models of this type can provide predictions of the overall temporal patterns of ecosystem structure and function that can be expected to accompany a given frequency and character of episodic disturbance. Such models can also be used to examine chronic disturbances such as acid rain and long-term climatic change. Predictive ecosystem models should be used in conjunction with some method of stratifying the inherent biophysical variability of the forest environment, such as B.C.'s biogeoclimatic classification system.

Introduction

Canada can legitimately be called a "forest nation". Forests cover a very large proportion of the Canadian landscape, and they have helped to mould the national character. They play a critical role in fish, water, wildlife and recreational resources, and forestry generates a very significant proportion of Canada's internal and export economies. In a rapidly changing world, it is therefore vital that Canada has a means by which to monitor the long-term condition or "health" of the forest environment. Faced with increasing pressure for both traditional and contemporary forest products, increasing pressure for recreational and other non-timber land uses, and increasing alteration of the chemistry and physical characteristics of the atmosphere, it is time to put in place a system by which we can monitor whether or not the forest environment is being degraded.

Two decades of concern over the impact of acid rain on lakes and rivers has revealed significant and unacceptable alterations in many aquatic ecosystems. Ecosystem parameters have been identified that permit the monitoring of this environmental impact of air pollution, and it is understandable that similar, relatively simple indices of the quality of the forest environment have been sought. For many years, no clear evidence of changing forest quality in response to acid rain was found. This has changed. The dramatic decline of forests in central Europe over the past decade stands as a clear warning of the potential consequences of failure to monitor accumulating effects of air pollution. Although the etiology of the forest damage in Europe (and alleged similar examples in high-elevation forests in some parts of the eastern and southwestern US) is still in dispute, the evidence is compelling that human-induced atmospheric alterations are intimately involved, and that there is a need to understand and monitor these socially, economically and ecologically dramatic events if we are to be able to design industrial and resource management policies that prevent, reduce or manage these impacts.

Unfortunately, monitoring the quality of the Canadian forest environment is not as straightforward as monitoring an aquatic environment. Whereas the structure and function of lakes may remain relatively constant year to year in the absence of human-related disturbance, most forests are constantly changing. The time scale of significant disturbance and recovery therefrom in forested ecosystems is generally very much shorter than in most lakes and rivers (low order streams may have much shorter time scales, due to their intimate interaction with the terrestrial forest ecosystem). Detection of human-induced change due to continuous chronic disturbance such as air pollution is complicated by the

effects of natural year-to-year climatic variation, and of the processes of natural succession as the forest continues to recover from the last disturbance.

In this paper, I will briefly review some of the sources of spatial variation in the physical environments in which Canadian forests develop, and the types of episodic disturbance that have resulted in today's mosaic of forest stands of varying structure, species composition and diversity, productivity, rate of change, and overall "condition" (nutrient and organic matter inventories and dynamics). Any attempt to monitor the "quality" of the Canadian forest environment which fails to account for the inherent spatial and temporal variability of our forests is doomed to failure. The paper then discusses the type of monitoring tool that I believe could be used to overcome these problems, and the paper will conclude with a brief introduction to an example of such a tool, the ecosystem simulation model FORCYTE.

Spatial and Temporal Variation in Canada's Forests

Four out of the five major types of world climate are represented in Canada, with most of the climatic variability occurring in the topographically complex western two provinces. We have arctic, alpine, sub-alpine, montane, boreal, sub-boreal, temperate (both mesothermal and continental), Mediterranean, dry forest, and semi-desert climates. Only tropical climates are not represented in Canada. Different types of forest are associated with each of these climates and within some of these major climatic types there is enough variation to result in significant variation in forest structure, composition and function within the climatic type.

Climate is not the only variable affecting our forests. Although some of the climatic variability is explained by varying topography, topographic variation also gives rise to patterns in soil conditions that result in differences in forests (e.g. soil depth, soil moisture, soil texture). Variation in glacial history is associated with variations in soil conditions, and the mineralogy and geology of the materials within the rooting zone can also produce dramatic differences in the character of the forest, often because of soil nutritional differences.

Forests have the innate ability to create their own environments. Given enough time (many centuries or even many millenia) without disturbance, the natural processes of ecological succession result in the laying down by forests of a blanket of organic matter (the forest floor) which eventually confers on the forest a considerable degree of independence from the underlying variation in soil physical and chemical characteristics. The result is a climax forest which exhibits much less spatial variation than would be expected based on the underlying physical and chemical variability of the landscape.

Such climax forests can be found in the humid mesothermal climates of the west coast, where the frequency of natural disturbance is low relative to the rate of natural succession and successional convergence (see discussion in Kimmins 1987). However, in most Canadian forests, disturbance from fire, insects, diseases and wind have historically been frequent enough to maintain the landscape in a patchwork of forest stands in various stages of recovery from disturbance. Add to this natural disturbance the widespread effects of forest harvesting, and you have a "patchwork quilt" of different and changing successional stages and ecosystem conditions. It is

against this complex patchwork of ever-changing conditions that we must design systems by which to determine whether or not human-induced changes in the historical frequencies of fire, insects, diseases and wind damage, forest harvesting-related disturbance, and human-induced changes in climate and atmospheric chemistry are resulting in unacceptable changes in the long-term condition of our forests.

Tools to be used in monitoring Canada's forests

Any attempt to monitor the condition of Canada's forests must, as a starting point, stratify the country into reasonably ecologically homogeneous units. Systems for doing this exist, and it is recommended that the design of any monitoring system be based on one or more of these systems. The complex biophysical variability of western Canada has been described in the biogeoclimatic classification system (Krajina 1965, Klinka et al. 1980, Kojima 1981), and this approach is being applied in modified form in the ecological site classification of Ontario conducted by the Ontario Institute of Pedology. Monitoring should be conducted at the biogeoclimatic subzone (or comparable unit) level, taking into account the variation in ecosystem types within a subzone.

Having identified a particular ecosystem type, site type, or ecosystem association (for definition of these terms, see the above references), it is necessary to establish the temporal pattern of ecosystem structure, condition and function that could be expected for a "healthy" ecosystem of that character at its particular age-since-last-disturbance, taking into account the type (e.g. fire, wind, logging), extent (area affected) and intensity (e.g. intensity and duration of the fire; whole-tree or stem only logging) of the disturbance. With so many variables influencing the expected

condition, it is difficult to imagine a monitoring system that did not involve some type of model, either tabular, pictorial, or, preferably, an ecosystem-level computer simulation model. Such models, if correctly formulated and calibrated, can be used to simulate various types and intensities of ecosystem disturbance at various frequencies, and to predict the associated temporal variation in ecosystem structure, organic matter and nutrient inventories, soil condition, and plant productivity.

There are several ecosystem level models currently available (see references in Kimmins and Sollins (in press)). One example is FORCYTE, an ecosystem-level forest, agroforestry or agricultural ecosystem management model. Only a brief description is given here. More complete descriptions can be found in Kimmins (1985, 1986); and Kimmins and Scouller (1987).

FORCYTE-11 is a modelling framework rather than a single model. It is a hybrid stand-level/individual tree model, and a hybrid historical bioassay/ecosystem process model (see above references for explanations). Because of its modular form, the model can be customized to permit it to be calibrated to simulate ecosystems as diverse as monoculture boreal forests, temperate mixed forests, temperate monoculture agriculture, and tropical agroforestry. It can also be used to examine the management of re-vegetation of mined land. In its present version, it cannot examine the effects of long-term climatic change, nor of acid rain, but its structure lends itself ideally to modification for these types of application.

The simulation approach adopted in FORCYTE is to take the historical pattern of plant growth on a particular site type

as the best measure of plant growth "strategy" and productive potential on that site type (this is referred to as the "historical bioassay" of the site for that species). This historical pattern, which becomes the basis for predicting future growth and "ecosystem condition", is modified through a simulation of the processes of nutrient and organic matter dynamics, of canopy light conditions, and of competition for light and nutrients. The process simulations determine whether the historical pattern of growth can be achieved under the future growing conditions that the user chooses to simulate. In a future version of the model (FORCYTE-12), explicit simulations of moisture and temperature effects are planned, this will render the model more suitable for research on long-term climatic change.

Figure 1 presents the flow chart of compartments and transfer processes that are represented in FORCYTE-11, while Tables 1 and 2 list the management actions, natural events, and soil processes that can be represented.

Use of models like FORCYTE-11 to monitor the condition of the forest environment

Because of the spatial and temporal complexity of the Canadian forest environment, because of the historical frequency of episodic forest disturbance, and because of "natural" climatic variation, it will be extremely difficult to detect changes in ecosystem condition caused by more continuous, chronic types of human-induced disturbance unless these changes are very dramatic. This has been the experience in European, Scandinavian and eastern US forests, where arguments still rage about whether forest decline and tree death represents a natural, episodic event in the life of those forest ecosystems, a totally human-induced event related

Figure 1. Major compartments and transfer processes represented in FORCYTE-11.

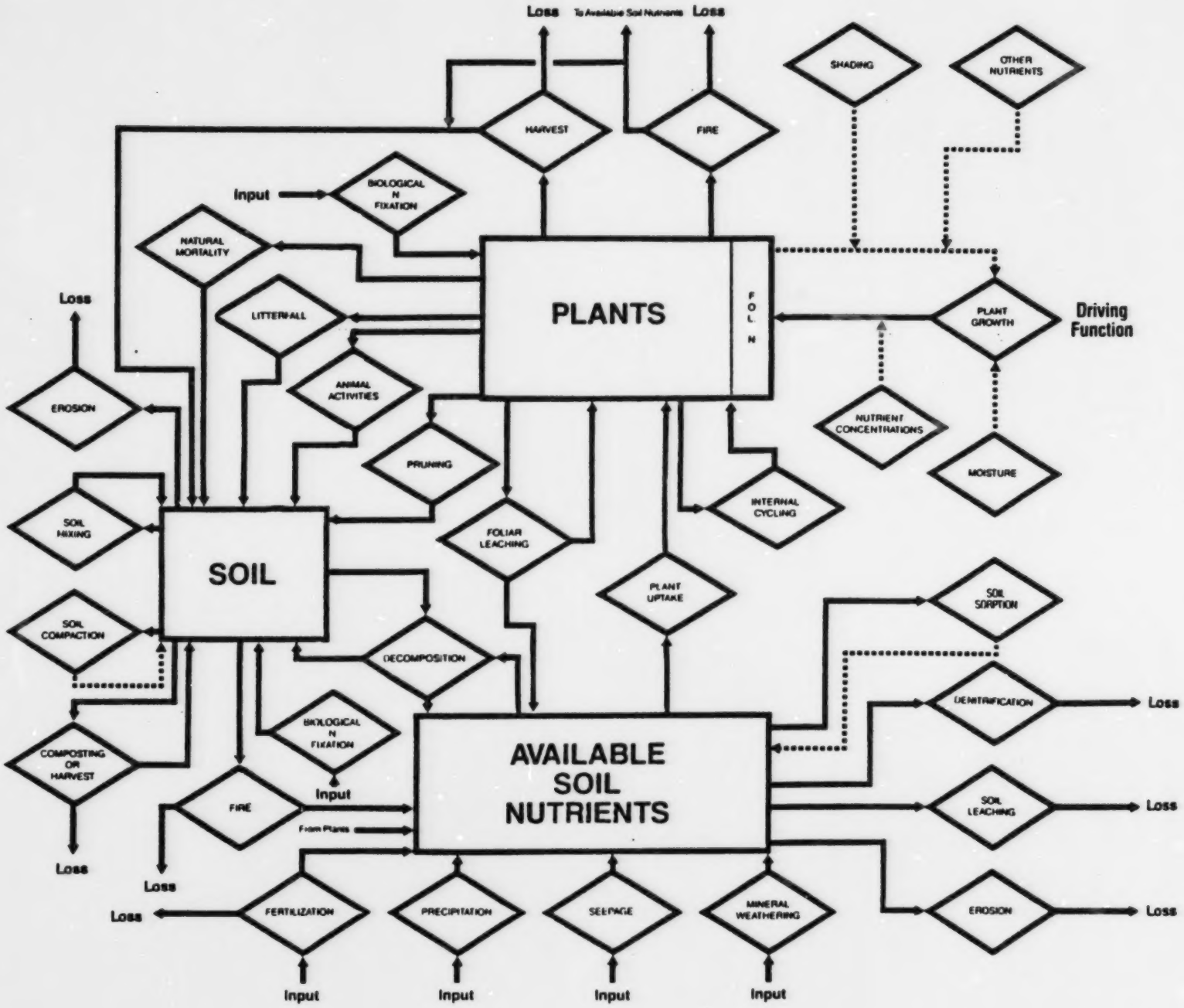
Loss
To Available Soil Nutrients
Loss
SHADING
OTHER NUTRIENTS
HARVEST
FIRE
Input
BIOLOGICAL N FIXATION
NATURAL MORTALITY
PLANTS
F O L I A G E N
PLANT GROWTH
Driving Function
Loss
LITTERFALL
EROSION
ANIMAL ACTIVITIES
NUTRIENT CONCENTRATIONS
MOISTURE
PRUNING
INTERNAL CYCLING
SOIL MIXING
FOLIAR LEACHING
SOIL
PLANT UPTAKE
SOIL SORPTION
SOIL COMPACTION
DECOMPOSITION
DENITRIFICATION
Loss
BIOLOGICAL N FIXATION
COMPOSTING OR HARVEST
AVAILABLE SOIL NUTRIENTS
Input
FIRE
From Plants
SOIL LEACHING
Loss
Loss
Loss
Loss
FERTILIZATION
PRECIPITATION
SEEPAGE
MINERAL WEATHERING
EROSION
Loss
Input
Input
Input
Input

Table 1. Management Options in FORCYTE-11.*

Site preparation	- mechanical or fire (ploughing, broadcast burn, windrow, pile-and-burn)
Regeneration	- planting (any size/age of seedling/sapling/tree), coppice/root suckering, or natural seeding; monocultures or mixtures
Weed competition	- for light or nutrients by herbs, shrubs, or non-crop trees. Control of competition (manual or chemical)
Stand density control	- spacing or pre-commercial thinning; random or other defined spacing strategy
Thinning (commercial)	- high, low, random, or other defined thinning regime
Final harvest	- clearcut harvesting
Utilization level	- any defined proportion of any plant (or soil) component may be harvested at any time
Rotation length	- annual cropping, or short, medium or long (e.g. centuries) rotations
Fertilization	- broadcast or spot; single or multi-nutrients; inorganic or organic
Pruning	- removal of any defined proportion of live and/or dead branches
Herbivory	- e.g. insect defoliation of trees; wildlife browsing on herbs or shrubs
Fire	- prescribed stand or slash burning, or wildfire
Litter raking/slash harvest	- harvest of ectorganic layer, or of logging/ thinning slash at any time. Upper soil layer(s) can also be removed

* The user decides which of these options are to be simulated, and how. Very simple or very complex scenarios can be simulated.

Table 2. Soil Processes or Management Impacts on Soil that can be Represented in FORCYTE-11.*

Organic matter decomposition, mineralization, immobilization
Humus decomposition and mineralization
Soil CEC and AEC, separately for organic matter and mineral soil
Soil sorption/desorption (e.g. of phosphorus)
Soil leaching
Soil mixing (soil animals, or mechanical mixing)
Root distribution by soil layers, according to nutrient availability
Allelopathic effects on decomposition
Organic matter substrate effects and plant effects on the ionic forms of nitrogen
Soil compaction and recovery therefrom
Soil erosion (sheet erosion, rather than mass wasting)
Denitrification (not presently operational)
Litterfall (and root mortality) inputs of organic matter and nutrients to the soil
Nutrient uptake from the soil and competition for soil nutrients by plants

* Because some of these processes are either poorly understood or poorly documented for a particular site, the user may wish to omit any or all of them from the simulation, and can do so. However, the user is reminded that omitting the simulation of a process that is known to be important is as large an assumption as including it, and may lead to as great or even greater error than including a conservative simulation of the process.

to air pollution, or some combination of the two (the most likely explanation). There are similar difficulties in attributing changes in ecosystem structure and function to episodic disturbances.

One solution to this difficulty is to use models like FORCYTE-11 to establish the "temporal fingerprint" of a particular forest site: the expected temporal pattern of ecosystem recovery following a particular disturbance. Ecosystems have an inherent "resonance frequency" (Kimmins 1970, 1973, 1987; Bormann & Likens 1979): the characteristic rate of, and time for recovery from a given level of disturbance. This is related to the concept of "ecological rotation" (Kimmins 1974) which suggests that the frequency & intensity of disturbance caused by forest harvesting must be related to the inherent speed of recovery of the ecosystem from the harvest disturbance. Models like FORCYTE can be used to establish "ecological rotations" and "resonance frequencies" for different sites, and thereby to establish acceptable deviations from long-term sustained ecosystem condition. The models can be used to predict the long-term pattern of fluctuations of ecosystem condition around the long-term mean that would be expected given a particular frequency & type of episodic disturbances. Deviations from this expected pattern can then be used as the index or "ecological indicator" of the effects of disturbances such as acid rain or climatic warming.

FORCYTE is available in both mainframe and microcomputer versions. FORCYTE-11 requires a 32-bit microprocessor if used on a microcomputer (either a 32-bit co-processor board, or a 386 microcomputer).

Conclusions & Recommendations

1. Monitoring the long-term condition of the Canadian forest environment must recognize the spatial and temporal variability and the dynamic (continually changing) character of that environment.

   The design of forest monitoring systems must include in the first phase the selection of an ecological classification system that stratifies the Canadian forest environment into units that have similar patterns of temporal change and response to disturbance. It is suggested that a system analogous to the biogeoclimatic system of BC, Alberta, and (in modified form) Ontario be adopted as the national foundation for forest monitoring.

2. Monitoring is required at two levels: monitoring the effects of acute, episodic effects, including harvesting effects; and monitoring the effects of chronic, continuous effects, including air pollution and climatic change. The latter cannot be done without considering the former, and the former will be complicated by the latter.

3. The temporal, structural, and functional complexity of the forest environment requires that we utilize ecosystem-level models to make predictions about future trends. Because of the complexity of such models, they must be implemented as computer simulation models. Purely historical bioassay models lack the flexibility needed in a monitoring and prediction system, and useable ecosystem-level process simulation models have not yet been successfully developed. It is recommended that one of the available ecosystem-level hybrid historical

bioassay/process simulation models be used to establish, for a series of benchmark sites representing the major forest types of Canada, the "resonance frequency", "ecological rotation", and expected pattern of fluctuations in ecosystem condition around a sustainable long-term mean condition. These parameters then become the "ecological indicator" for these sites. Periodic monitoring of current ecosystem condition can be compared with this "temporal fingerprint" to detect deviations that may indicate a change in long-term forest ecosystem quality.

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REDIS[illegible]BUTION OF ^{137}Cs AS AN EXAMPLE OF A CHEMICAL INDICATOR OF ENVIRONMENTAL STRES[illegible]

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INTRODUCTION

The analysis of ^{137}Cesium concentrations in terrestrial and aquatic sediments is becoming a widely used indicator of the extent of soil erosion. By tracing the radioactive isotope through a watershed, the researcher can both retrospectively assess the amounts of soil loss and gain which have occurred and diagnose those portions of the landscape most susceptible to erosion. The implementation of conservation measures on these targeted areas will reduce the input of sediments into the adjacent aquatic systems. The analysis of ^{137}Cs concentrations also supplements data gathered on other soil deterioration problems such as organic matter degradation.

The adoption of ^{137}Cs concentrations as a chemical indicator can be examined in the framework of the criteria for chemical indicators discussed at the Workshop on Ecological Indicators. These criteria for adoption of an indicator specify that the indicator should a) be applicable nationally or at least over a broad biophysical region, b) be logically related to a stress caused by human activity, c) be scientifically defensible, d) have an adequate historical record and projected availability of data sets, e) have a high reliability and consistency of measurements, f) be simple to gather and analyze, and g) yield quantitative data. Beyond these general criteria, it was also suggested that a chemical indicator should be capable of monitoring the flux of sediments between ecosystems.

The purpose of this report is to examine the theoritical, methodological, and analytical basis of the use of ^{137}Cs concentrations as a chemical indicator. The information presented is related back to the criteria for adoption of an indicator as outlined above. Although the specific technique itself is only applicable to a specific type of stress, the development of a set of criteria for adoption of an indicator is common to a range of environmental science disciplines.

NATURE OF THE STRESS

Analysis of ^{137}Cs concentrations is used to assess the extent and severity of accelerated soil erosion, which is widely recognized as one of the major forms of soil degradation in Canada. Although soil erosion itself is a natural geomorphic process, the rate of erosion greatly increases with land clearing and cultivation. The increase in mechanization in agriculture and the trend towards monoculture of wide-row crops such as corn and potatoes, especially in Central and Eastern Canada, has greatly exacerbated the problem.

In the context of the signs of ecosystem dysfunction used by Rapport et al. (1985) soil erosion causes changes in nutrient cycling due to the lateral transport of nutrients (both as organic matter and as nutrients bound to colloidal material) by wind and water. The nutrients are either redistributed within the field or are exported from the field into adjacent waterways. Despite this alteration of the natural nutrient cycle, many of the subsequent changes in the ecosystem normally associated with such a disruption are masked in the managed agricultural ecosystem by increased applications of fertilizers and related soil admendments such as lime. Much of the widely documented increase of fertilizer and admendment use in Canada (e.g. Table 3.1.37, Human Activity and the Environment (1986)) can be attributed to the influence of soil erosion.

Despite the widespread recognition of the problem of soil erosion there is a distinct paucity of data on the extent of the problem. The data base in Canada up to 1982 was derived either from long-term plot experiments at a limited number of sites or from the application of the Universal Soil Loss Equation (Wischmeier and Smith, 1965). The latter technique predicts erosion rather than assessing the actual amount of erosion which has occurred. The increased popularity of the ^{137}Cs technique since 1982 is due to this lack of data on the actual amounts of erosion in Canada.

THEORITICAL AND METHODOLOGICAL BASIS OF THE ^{137}Cs REDISTRIBUTION TECHNIQUE

Cesium-137 was originally deposited on the landscape as radioactive fallout from the nuclear bomb tests of the late 1950's and early 1960's (Figure 1). The amount of initial input was broadly similar in wide geographic zones and variations within a latitudinal zone correspond to differences in mean annual precipitation in the zone (Wise, 1980).

Research during the period of highest fallout (1957-1964) documented that the ^{137}Cs was immediately bound to micaceous colloids in the uppermost 10 cm of the soil column (Tamura and Jacobs, 1960). Uptake of the isotope by plants and vertical leaching in the soil column were minimal and, on the field scale, the amount of input was relatively even across the field.

The use of ^{137}Cs as an indicator is based on the tighr bond between the ^{137}Cs and the colloids. In the years following peak deposition redistribution of the colloid-^{137}Cs complexes has occurred due to the combined effects of water, wind, and tillage erosion (Figure 1). Areas of the field experiencing erosion will have lower concentrations of ^{137}Cs than adjacent, uncultivated fields that have not experienced accelerated erosion. Areas within the field which have ^{137}Cs present below the plow layer have had deposition of sediments and net soil gain. If export of ^{137}Cs-colloid complexes from the field has occurred, the concentration of ^{137}Cs in sediment cores from aquatic ecosystems may be assessed to determine the sediment loading into the adjacent waterways.

The relationship between ^{137}Cs redistribution and observed soil loss or gain was first tested by Rogoowski and Tamura (1970) using artificially applied ^{137}Cs on small erosion plots. They found that losses of ^{137}Cs were significantly related to measured soil losses. A recent analysis of ^{137}Cs losses and actual soil losses from research plots at the University of Guleph again demonstrated that a significant linear relationship existed between soil loss and measured ^{137}Cs losses (Kachanoski, 1987). Hence the relationship between the indicator and the stress

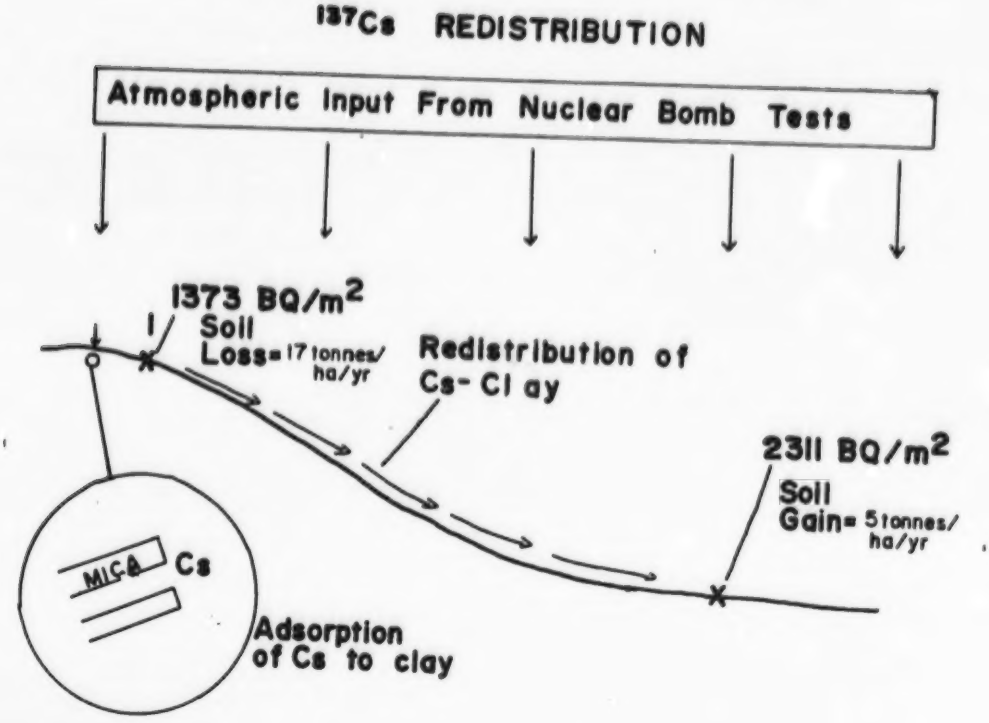

Figure 1: Redistribution of ^{137}Cs in the Landscape.

has recieved a high degree of scientific validation.

The assessment of the actual amount of ^{137}Cs redistribution involves both field sampling and laboratory analysis. The field sampling techniques have differed greatly between researchers and this lack of a standardized sampling program limits the comparisons which may be made between existing studies. A standard sampling program for a province-wide survey in Saskatchewan involved sampling of the soil at 36 sampling stations in a field. The sampling stations were located at grid intersections of a square grid, with a spacing of 25 m between stations (Pennock and de Jong, 1987).

Laboratory analysis of ^{137}Cs concentrations is accomplished using gamma spectroscopy. The first Canadian system, which is located at the University of Saskatchewan, uses a high purity Ge-crystal coupled to a multichannel analyzer (de Jong et al., 1982). Cesium-137 contents are initially calculated on an area basis (Bequerels/cm^2) which are readily converted to tonnes/ha using the bulk density of the sample. A value in tonnes/ha/yr is calculated by dividing this value by the years elapsed since peak fallout (1963).

In summary, the use of ^{137}Cs in all regions of Canada is possible due to its ubiquitous distribution. The technique has recieved a high degree of scientific validation, and the nature of the technique - the comparison of cultivated sites to adjacent native sites- readily yields a historical contrast. The data is quantitative and can readily be converted units of direct signifigance in erosion research.

EXAMPLES OF RESEARCH USING ^{137}Cs REDISTRIBUTION

Two levels of research using the ^{137}Cs redistribution technique have been undertaken in Canada. The first level consists of preliminary or reconnaissance research, where a limited number of sites have been used to test the applicability of the technique in a specific environment (de Jong et al., 1982, de Jong et al., 1983, Kachanoski and de Jong, 1984, Gregorich and Anderson, 1985, de Jong et al., 1986, Kiss et al., 1986, Kachanoski, 1987). The second level consists of intensive use of the

technique in an area with sufficent replication for statistical analysis (Martz and de Jong, 1987, Pennock and de Jong, 1987, Pennock and de Jong, unpublished data). The results from this latter group of studies are used in the following paragraphs.

Several consistent themes have emerged from the existing research. The first is that the actual amounts of erosion occurring are much higher than previously thought. The average soil loss for sampling sites which experienced soil loss is between -16.2 to -24.2 for a range of Saskatchewan soils (Table 1). This loss is several times higher than the estimates prior to application of the ^{137}Cs technique (Nicholaichuk and Read, 1978 and Toogood, 1963). The losses are also several times higher than the tolerable soil loss (that loss which will allow current agricultural practises to be sustained) for Saskatchewan.

A second major finding of the existing research is that the majority of sampling stations in the fields are losing soil, which is being concentrated in spatially restricted landscape positions (Table 1). For example, Martz and de Jong (1987) found that 90% of the soil deposition was being concentrated in only 3% of the basin they examined.

All but one of the sites assessed are experiencing a net export of soil out of the field (a negative net soil loss or gain in Table 1 indicates a net export of soil). This exported sediment is the input into the adjacent fluvial and lacustrine systems. Although studies on the ^{137}Cs contents of fluvial and lacustrine cores have not been conducted in Saskatchewan, the procedures have been developed and utilized elsewhere (Wise, 1980).

The results of ^{137}Cs studies have also been used to augment research on organic matter degradation and nutrient losses. Both Voroney et al. (1981) and Gregorich and Anderson (1985) have used ^{137}Cs redistribution to estimate the rate of lateral movement of organic erosion by erosion. This estimate allowed them to rigoursly evaluate the rate of in-situ organic matter decomposition due to cultivation

Table 1: Soil loss or gain values calculated for the ^{137}Cs technique for Saskatchewan soils (all soils are Chernozems with dominant slopes between 5-9%).

Geographical Location	Soil Type	Net Soil Loss/Gain	Average Soil Loss/Gain		% Sampling Stations with Soil Loss
			Eroded Stations	Depositional Stations	
		Tonnes/Ha/Yr			
Stewart Valley[1]	Brown	-7.5	-27.2	18.9	53.3
Assiniboia[1]	Brown	-12.6	-23.7	9.7	66.7
Stoughton[1]	Dark Brown	-16.1	-24.2	33.6	86.1
Glenavon[1]	Dark brown	-11.9	-20.1	22.3	80.6
Viscount[1]	Dark Brown	-12.9	-24.1	25.8	77.8
Saskatoon[2]	Dark Brown	0.6	-18.0	24.2	58.0
Hafford[3]	Black	-16.9	-27.2	23.1	83.0
"	"	-9.5	-16.2	16.3	89.0
"	"	-10.8	-20.6	26.2	87.0

[1] Pennock and de Jong (1987) Unpublished data

[2] Martz and de Jong (1987)

[3] Pennock and de Jong (1987)

Pennock and de Jong (1987) used ^{137}Cs to examine the relationship between slope morphology and observed erosion. Significant differences in erosion reates were observed between different landform configurations, and these differences formed the basis of a landform element classification. The classification can be used to map the erosion hazard in unsampled sites, and mapping programs such as this are a second phase in developing a technical information system for environmental management (H. Regier, Pers. comm.,workshop presentation).

In summary, the application of the ^{137}Cs redistribution technique has, as of now, only been undertaken in Saskatchewan. Results from these studies have indicated that a higher level of stress is occurring than previously documented. The technique can also be used to increase the reliability of other indicators of ecosystem stress such as organic matter decomposition. Finally the technique readily lends itself to mapping of the stress and extension of the management program to unresearched areas.

SUMMARY

The analysis of ^{137}Cs has been used to illustrate how the criteria for a chemical indicator may be developed and evaluated. Methodologically the technique meets the seven criteria outlined in the introduction. The analysis of the results of the technique have already yielded a considerable amount of information directly related to the stress in question, soil erosion. Problems with the future use of the technique are likely to be more institutional than methodological, because the existing facilities, which are largely located in academic institutions, are unlikely to be able to engage in the type of national-scale assessment required to amass a suitable state of the environment data base.

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THE USE OF LICHEN GROWTH ABNORMALITIES AS AN EARLY WARNING INDICATOR OF FOREST DIEBACK, Martha G. Scott and T.C. Hutchinson, Institute for Environmental Studies, University of Toronto. Toronto, Ontario. M5S 1A4.

A/ OBJECTIVES

Recent studies by cloudwater chemists (Walman et al. 1982; Schemenauer 1986; Shemenauer and Anlauf 1987) demonstrate that the acidity, duration of episodes and dosage of sulfate and nitrate in high-elevation fogs is potentially more damaging to vegetation than that found in regular wet deposition or 'rain'. For example, the pH of fog episodes at the summits of two mountains in Quebec in late 1985 was 3.8, whereas precipitation pH values for the same locations were approximately 4.3 (Schemenauer 1986). These acidic mists, when combined with the elevated levels of ozone which also occur at high altitudes have led scientists to speculate that this mixture of atmospheric pollutants may be responsible, in part, for the extensive declines in red spruce, balsam fir and other coniferous and broad-leaved species which are now occurring at mountain-top locations throughout much of eastern North America. Alternative hypotheses to explain forest dieback include the occurence and onset of soil and nutritional deficiencies , inappropriate forest management practices, insect and fungal pathogens and long-term fluctuations in climatic variables. Although atmospheric chemistry is being monitored through the Chemistry of high elevation fog (CHEF) project, there have been few attempts to directly correlate levels of toxic inputs with characteristics of vegetation at the study sites. The objective of our current study is, therefore, to examine the potential of some forest lichen species as early warning indicators of dieback at mountaintop sites where atmospheric pollution levels are being carefully measured on an ongoing basis.

Historically, lichens have been shown to be sensitive environmental indicators (Gilbert 1963; LeBlanc and Rao 1966; Leblanc and de Sloover 1970; Hawksworth and Rose 1976; Sigal and Nash 1976; Seaward 1987). The presence and absence of key species has been used to trace levels of SO_2, O_3 and fluoride emissions near industrialized centres. However, the species selected for use in this study have a number of morphological and anatomical attributes which may make them especially suitable for diagnostic studies. The intent is not to use presence or absence data but to deliberately transplant to all sites healthy lichens selected for their potential to develop particular abnormalities when stressed and to study the occurence of these abnormalities in natural field populations.

B/ BACKGROUND STUDIES

The concept of using growth pattern irregularities to indicate areas of toxic fogs and precipitation arises from recent studies conducted at Burt Lake, near Kirkland Lake in northern Ontario, in which boreal forest understorey vegetation in permanent plots received periodic sprays of simulated acid precipitation (Hutchinson et al. 1986; Hutchinson et al. 1987; Scott and Hutchinson, in press; Scott and Hutchinson, in prep.). Caribou-forage lichens, especially Cladina stellaris, C. rangiferina and C. mitis comprise a high percentage of the ground cover in open, xeric sites beneath a predominantly jack pine (Pinus banksiana) canopy. A number of lichen parameters including percentage ground cover, photosynthetic rates, growth characteristics and tissue chemistry were monitored to determine the long-term effects of repeated acid rain episodes.

Following five years of spraying with 'artificial' rain of either pH 3.0 or pH 2.5 made up of a 2:1 ratio of sulfate to nitrate, both C. rangiferina and C. mitis showed abnormal branching patterns not previously reported. Under natural field conditions, podetia (single branched units) of the genus Cladina have an upright orientation and increase in height by the yearly production of a new 'internode'. Branching occurs by dichotomization of podetial tips. Lower internodes elongate less rapidly due to shading from above. In plots receiving sprays of pH 3.0 or 2.5, 10 to 15% of the population of C. rangiferina and C. mitis developed stunted branching systems on mature, fully-elongated internodes where little new growth would be expected to occur. In contrast, none of the individuals from unsprayed 'control' plots or from plots that received rain of pH 4.0 or 5.6 developed this 'dwarf' branching. Microscopic examination of the branching pattern revealed that dichotomizations occur rapidly, and newly initiated tips form numerous sexual structures or apothecia.

These unique growth abnormalities have not been reported in the literature. The dwarf branching occurred only when the plants were given acidic sprays and therefore may be a valuable diagnostic tool. Production of numerous reproductive structures may also be a response to atmospheric pollution, particularly that of ozone. Rosentreter and Ahmadjian (1977), in their examination of Cladonia arbuscula and the algal symbiont of C. stellaris, reported increases in chlorophyll content and growth stimulation at 100 ppb of ozone. They suggested that this response could account for the proliferation of lichens in mountaintop environments. Anderson (unpublished) also commented that ozone may stimulate podetial production in C. coniocraea and apothecial production in Hydrotheria venosa.

There is evidence to suggest that long-term exposure to pollutants may cause shifts in patterns of carbohydrate allocation in algal and fungal components of the lichen symbiosis. At our Burt Lake sites, the alga of the three lichen species developed numerous, large lipid deposits and accumulated starch following five years of spraying with acidic solutions. The phenomenon of carbohydrate sequestering has been reported for both lichens and higher plants exposed to a variety of anthropogenic stresses (Silva Pando and Ascaso 1982; Winters 1982; Scott and Larson 1986).

The next phase of our research involves studying the lichen flora at forested, mountaintop locations in Quebec and New England where CHEF and its American counterpart are monitoring cloudwater chemistry and ozone levels on a year-round basis. Dieback of coniferous tree species is severe at the study locations. We are hoping to obtain correlations atmospheric chemistry and lichen tissue chemistry and, at the same time, to determine whether the morphological and anatomical aberrations described above occur naturally when lichens are exposed to ambient levels of acid fog and ozone.

C/ STUDY SITES AND SAMPLING PROCEDURES

i) The control site: Although it is virtually impossible to select an appropriate control for this sort of research, lichen material from the Burt Lake site is being used as a baseline for comparison with samples from the high altitude locations.

Burt Lake is at the southernmost fringe of the boreal forest. It is an area relatively free from natural acidic deposition and contains species similar in microhabitat and physiology to those found at altitudes greater than 800m. Cornus canadensis, Vaccinium sp. and a number of the feather mosses are common components of the understorey in both systems. Coniferous trees predominate in both regions, although jack pine and black spruce, abundant in boreal forests, are replaced by balsam fir and red spruce in the more southerly, mountaintop forests. A number of the epiphytic lichens including Hypogymnia physodes, Cetraria pinastri, Parmelia sulcata, Evernia mesomorpha and the genera Usnea and Bryoria (different species) are also abundant at both sites, thus affording the possibility of reciprocal transplant experiments.

ii) High-Elevation Sites: Mount Tremblant and Roundtop Mountain in Quebec and Whiteface and Camel's Hump mountains in New England are being used as high elevation sites for this project. Because of the similar nature of the reported dieback in Norway spruce at high altitudes in Europe, material was also collected from several locations in West Germany, close to air quality monitoring stations for levels of SO_2 and ozone. Sites in the Black Forest, the Hartz mountains near the East German border and near the Czechoslovakian border were sampled and the same or similar species of epiphytes harvested. Trees from all sites were sampled at a range of altitudes on each mountain, i.e. from 600 to 100 metres.

iii) Low-Elevation Sites: Sudbury, Ontario and the Bay of Fundy in New Brunswick have been selected as potential low elevation sites. In the first case, the choice of Sudbury hinges on its long-term history of exposure to SO_x fumigations from local nickel and copper smelters. Elimination of many higher plant species, such as white pine, feather mosses and lichen epiphytes, occurred within a 10 - 15 km radius of the smelters. Leblanc and Rao (1966) reported morphological and anatomical abnormalities in semi-tolerant lichen species such as Parmelia sulcata. Since the construction of the superstacks in 1972, the intensity of the emissions has decreased considerably, and more sensitive species, such as C. rangiferina and C. mitis are beginning to reappear at previously decimated sites. For the purposes of this study, material will be collected near the point source of the emissions and southwards along the plume trajectory.

Recently, acid fog has become a concern in New Brunswick forests southwest of the Bay of Fundy where birch dieback is occurring. The acid fog at this low-elevation site provides the opportunity to discriminate between the effects of altitude and low pH on growth characteristics and tissue chemistry.

iv) Sampling Procedures: At both high and low elevations, ten trees of similar diameter were selected. The health of the trees was subjectively rated on a scale from one to five; with one being 'healthy' and five being 'dead'. The percentage cover of epiphytic lichens was estimated on a one metre area of the trunk and samples of the dominant species were collected for laboratory analyses. Because of its wide geographical distribution, Hypogymnia physodes was chemically analysed and used for physiological and morphological studies. Samples of soil-growing Cladina species were also collected where possible.

D/ MAJOR TYPES OF ANALYSES

i) Chemical analyses of lichen tissues and substrates: Comparisons in chemical composition between the same lichen species from the different sites should allow an assessment of whether acid leaching of key nutrients is taking place, of whether the lichens are accumulating potentially toxic levels of elements such as Pb, Cd and Zn and of whether the levels of the elements reflect the health of the plants as determined by the various methods of the study. Analyses for Ca, K, Mg and Na will be performed using a flame photometer and an atomic absorption spectrophotometer used in the flame emission mode. Fe, Zn, Cd, Pb, Al and Mn will be analysed in all matrices using a Perkin Elmer SP 460 atomic absorption spectrphotometer, using appropriate acid digestions. Confirmatory analyses will be made using inductively coupled plasma emission (ICP) on selected samples. For all of the above, reference standards will be used to determine the accurace and reliability of the analysis. S and N will be determined using a Leco furnace and P will be determined using an auto-analyser. Levels of sulfate and nitrate will be determined using a Dionex ion chromatograph.

ii) Morphological and Anatomical Analyses: Using a dissecting microscope, branching pattern or thallus lobe abnormalities will be observed and photographed. The number and type of reproductive propagules will be noted. In the case of C. rangiferina, podetial height and dry weight measurements will be made separately on the basal and upper, photosynthetically-active portions. Observations will be made on the algal and fungal components of both branched and leaf-like types of epiphytes. 'Dwarf' branch complexes will also be examined. The protocol used to prepare lichen tissue for light and transmission electron microscopy has been described previously (Scott and Larson; 1984, 1986). Using TEM, the general condition of the cytoplasm, algal and fungal cell wall characteristics, chloroplast morphology and peripheral cell organelles will be described. Amount and distribution of algal photosynthetic reserves, i.e. starch and lipid, will be quantified, if possible.

iii) Reciprocal Transplant Experiments: Lichens from the relatively 'clean' Burt Lake environment will be transplanted to a range of altitudes including the summits of each of the mountains for two years. Although we do not know how long an exposure to the stress is required to induce branching abnormalities or other morphological responses, changes in tissue chemistry, or even heavy metal accumulation, may occur following short duration exposure to acidic fog and ozone.

Although there are no chemical data yet available, the study sites have been selected and the trees rated and sampled. Several genera of epiphytes from the highest altitudes, especially Pseudevernia and Evernia have a proliferation of asexual propagules on the thalli. Isidia were found in greater numbers on lichens at mountainous locations than on lichens from low altitude sites.

In conclusion, it is hoped that data from this study may have predictive value in indicating locations where cloudwater chemistry and ozone dosage are sufficiently toxic to induce forest dieback. If morphological aberrations can be shown to be related to atmospheric inputs, then the lichen species which respond in this manner would make excellent indicators of environmental quality. All

of the epiphytic species, especially Hypogymnia physodes, have a wide global distribution at both high and low altitude locations. The species are sufficiently tolerant of high acidity to respond gradually over a long period of time and, in fact, to show some stimulation of productivity. This is unlike the situation for SO_2-fumigated lichens where complete elimination of most species occurs rapidly. Epiphytic lichens are easily collected and the morphological abnormalites can be identified with a minimum of training. In addition, because of the high percentage cover of epiphytes on the trunks and branches of both coniferous and deciduous tree species, there may be significant interactions between atmospheric chemistry, the lichen component and the underlying vegetation and soil. The lichen interface may represent a more valued ecosystem component than previously recognized.

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PUBLIC PARTICIPATION AND VOLUNTEER HELP IN MONITORING PROGRAMS: AN ASSESSMENT,
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A number of opportunities exist for involving the public in environmental monitoring. This paper outlines some examples where this has been done, evaluates these examples, and then summarizes some of the benefits as well as the disadvantages of this approach.

Case 1: Wildlife Supplied by Hunters.

This information was given on request from A.W. Diamond, Coordinator CWS-LRTAP, NWRC, Ottawa.

Inuit hunters who had been contacted previously supplied tissues from carcasses of polar bears which they had shot in the arctic. The tissues were used for determination of heavy metals, essential elements and toxic organic chemicals by the Canadian Wildlife Service. Analysis of the results confirmed the usefulness and suitability of these tissues for monitoring the environmental concentrations and geographic distribution of several of chemical elements and compounds in most areas of the Arctic (Norstrom et al. 1986). In another study of metal residues in fish-eating wildlife in Ontario, fur trappers supplied carcasses of mink and otter (Wren and Stokes 1986). More recently, road-kills were used to study the suitability of grey squirrels as environmental monitors of lead and cadmium (Murray 1987). Road-kills, contributed by the public, are routinely analyzed for contaminants and stored in the Tissue Bank of the National Wildlife Research Centre.

Case 2: Self Help Program, Ontario Ministry of the Environment.

This information was supplied by Murray German, Chief, Water Resources Assessment, Technical Support Section, Ontario Ministry of the Environment, Southeastern Region.

The problem of eutrophication of recreational lakes became a major concern for cottagers in the late 1960's. The Ontario Ministry of the Environment conducted detailed water quality studies in many lakes, but the Ministry did not have the resources to do the continuous monitoring that was needed. This is where the cottagers help the Ministry as well as helping themselves, towards the objective of understanding year-to year changes and assessing long-term trends.

In 1971, the Ministry began a program in which cottage associations were provided with materials and information to establish their own long-term water quality monitoring schemes. Cottagers measured Secchi-disc depths every two weeks and collected water samples for chlorophyll analysis. The samples were analyzed for chlorophyll at the Ministry Laboratory. In the Southeastern Region 27 lakes were continuously sampled for 10 or more years. Approximately 90 to 100 lakes were sampled annually, with a few replacements each year, totalling 150 lakes.

The long-term trends showed that water quality in the recreational lakes had not been deteriorating. Water quality was expected to deteriorate in the 1960's but, in virtually every lake that was monitored, water quality conditions fluctuated within values that were "normal" seasonal variations.

The cottage associations participating in the program have developed an improved understanding of the methods and parameters involved in water quality monitoring, as well as an improved appreciation for environmental protection. They have provided the Ministry with valuable data in a truly cooperative program.

Case 3: Shoreline Restoration: Quebec and Ontario.

Development around lakes can often lead to significant changes in the lake ecosystem. The Quebec Ministry of the Environment has developed a shoreline restoration program involving the participation of citizens' groups or associations that have an interest in protection and restoration of the natural environment. The goal is to re-establish natural vegetation on shorelines. The Ministry provides seeds and plants (free of charge), to be planted by citizens. The program has been operating for nearly 20 years in Quebec.

In 1984 this program was extended to Ontario. Here the Ministry of Natural Resources in conjunction with the Ministry of the Environment provides technical information about the plants and planting techniques to cottage associations. The program is designed to restore a band of vegetation of at least 10m width around the lake. In Ontario the program is conducted by volunteers, with technical guidance from government agencies. While this is not monitoring in the strictest sense, there is an element of monitoring involved, and the program is another example of the spirit of cooperative volunteer programs. The residents of Christie Lake in eastern Ontario not only do the planting for their revegetation but also collect cuttings from the natural vegetation in the area. These cuttings are then rooted in a special nursery established on donated property.

Case 4: Tree Watch Survey, University of Toronto.

Scientists at the Institute for Environmental Studies at the University of Toronto have designed a one-page questionnaire (10 questions) concerning tree die-back in various regions of Canada and the United States. The questions address specific symptoms of trees, degree of stress, location of stress on the trees. The participants are also asked to consider the possible causes of the stress that they describe: e.g. could it be road salt, animal damage, etc.?

This questionnaire will be published (hopefully) in Harrowsmith during the summer of 1988. The results of the survey will be published in a subsequent issue of the same journal.

Case 5: "Watch" Bees Program in British Schools.

In England, scientists recently noted a decline in some species of bumblebees in certain areas. The "watch" program involves collection of information by school children concerning bee distribtuion, bee diversity, and the plants preferred by bumblebees. The scientists instruct the school teachers who in turn provide instruction to the children. The scientists feel that this type of information may eventually help them in solving the riddle of the bumblebees. It is probable that other factfinding missions may develop as a result of this initiative.

Discussion and Comments.

Before critically examining the scientific merits and disadvantages of the approaches described here, it seems important to address the social, educational, and economic aspects of volunteer involvement in environmental monitoring. There is no question that an essentially untapped pool of skill and/or enthusiasm exists in a number of sectors of the public. Not only the various types of citizen groups such as amateur naturalists, ornithologists, anglers and hunters, and cottagers can be called upon to participate in observing and recording information. Groups or classes of young in schools or youth groups or clubs also represent potential volunteers. Volunteer assistants develop a sense of being involved personally in a particular problem that is an obvious social benefit. The problem can change from a "them" and "us" situation (e.g. in the case of pollution) to a sense of cooperation resulting in a replacement of frustration by satisfaction and understanding.

The educational component is equally important. In the example of the water quality monitoring program, the cottagers have developed an improved understanding of the water quality conditions in their lakes. Public meetings have reinforced the sense of involvement as well as the instructional component. In the tree die-back example, which is still in the future as far as results are concerned, it will be possible to extract additional information concerning attitudes. For example, how many people are sufficiently concerned about our forests to participate in the questionnaire? From what geographical region and educational level do the respondants come? On the scientific side, it is possible that the respondants may pinpoint areas of tree die-back that the scientists have not yet examined.

There were individual examples at a very informal level, during the planning and execution of the mink and otter study, when the trappers' observations were of considerable value to the scientists. One should not underestimate the "wisdom" of age and the potential value of anecdotal information, especially of an historical nature. It is well known that for a number of the more insidious current environmental problems, lack of historical information hinders the interpretation of current data particularly in terms of trends. A few hours spent in conversation with an "elder" can be remarkably rewarding for the scientist, in addition to providing the social benefit for the non-scientists, discussed above.

Clearly there are also financial benefits for the environmental agencies and researchers. Volunteers are usually working without pay, or for very nominal fees. They can produce information quite quickly, and since the volunteer work is usually outside normal business hours, helpers can make observations at odd hours, early in the morning or at night. This may represent a significant advantage for some biological phenomena. The feasibility and cost of using paid professional help for such observations could be prohibitive.

Volunteers can also cover geographical areas that are not accessible to the usually small technical staff associated with many research and monitoring programs.

There are some disadvantages, that dictate the scope and level at which one should contemplate involving volunteers in monitoring programs. Reliability has to be questioned in two aspects. The first concerns the level of commitment, particularly in terms of long term studies. While there has been an excellent degree of commitment in some cases, the fact remains that volunteers are just that, and the scientist has no control over other factors which might curtail an activity, and has no right to make demands upon the volunteers. Generally speaking, the experiences recorded have been extremely positive, with a high degree of commitment and reliability, but it is a potential problem. The second type of reliability, and one which opponents of the concept tend to emphasize most frequently, has to do with the quality of the data produced, and the extent to which quality assurance/quality control can be asserted. Clearly in planning studies and surveys, the scientist or manager must have a realistic perception of the skills and abilities of the volunteers. These will vary from amateur naturalists who may be considered experts in their own fields, to young untrained and perhaps over-enthusiastic school children.

Objectivity can be difficult to achieve. For example, certain citizens' groups that are formed in a climate of activism, may feel compelled to dramatize or "expose" a problem, and this clearly can invalidate the findings. The most important message to be gleaned from these potentially serious disadvantages is that studies, surveys, and data collection which use volunteer help are no different in terms of the principles of scientific design than any other study. The methods should be appropriate to the skills and equipment available, as well as to the questions that are being addressed. The data should be verified by

"spot" checking wherever possible, and the standards for quality control should be set at the initiation of the project. Large sample sizes are recommended in order to compensate for individual biases.

However, as we have shown, the information which can be collected falls into several categories, including:

a. Opinions, from questionnaires for the most part,

b. Objective factual information, e.g. in the tree survey, people are asked "do symptoms include...." followed by specific description,

c. Measurements, such as the secchi disc values, and

d. Collections of samples, such as the carcasses, as well as (not mentioned here) samples of hay from farmers (for protein analysis), or soils (for pesticides).

The relative importance of long-term commitment and scientific data quality varies with the type of activity. Questionnaires do not require long-term activity, and carcass collection has minimal scientific requirements. The lake monitoring has requirements in both areas. Therefore, the investigator must have a clear goal in mind when selecting an approach, taking into account the interests and skills of the volunteers.

In conclusion, based on past experience and review of the experience of others, the authors of this paper consider that with the proper caution and appropriate design, the use of volunteer involvement in monitoring schemes should be given a great deal of attention and support.

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APPENDIX A

Participants at May 27-29, 1987 Workshop

LIST OF PARTICIPANTS AND INTERESTED PARTIES

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APPENDIX B

Programme for May 27-29, 1987 Workshop

WORKSHOP ON ECOLOGICAL INDICATORS MAY 27-29, 1987

Keynote Speakers

Wednesday, May 27 - Plenary Session, Series A

2:00 - 5:00 p.m.

1 David Rapport, Statistics Canada, Ottawa.
Criteria for Indicators.

2a) Peter Hodson, Fisheries & Oceans Canada, Burlington.
Indicators at the Species Level.

b) David Bernard, ESSA Ltd., Vancouver.
Indicators at the Community and Systems Level.

c) Dan Pennock, University of Toronto, Geography, Scarborough College, Toronto.
Soil Structure and Organic Matter Decline as Example of Chemical Indicator.

8:30 p.m. Reception at **Carlton Inn**, 30 Carlton St. in "Windows" restaurant.

Thursday May 28

9:00 - 11:00 a.m. Pamela Stokes will chair Series A Plenary Sessions and the four speakers will chair the work groups arising from their respective topics.

Rapporteurs: - Kristin Day
Gail Krantzberg
Magda Havas

11:30 - 12:30 p.m. Report on work groups, Series A, by rapporteurs, in plenary session.

12:30 - 2:00 p.m. LUNCH (Provided at IES)

2:00 - 4:00 p.m. Plenary Session, Series B

3a) Henry Regier, University of Toronto, Zoology and Environmental Studies, Toronto.
Indicators and Assessment of Fisheries.

b) Hamish Kimmins, University of British Columbia, Forestry, Vancouver.
Indicators & Assessment of Forests.

c) Ted Huffman, Agriculture Canada, Ottawa.
Methods of Assessment for Soil Sustainability.

4:00 - 5:30 p.m.	Tom Hutchinson will chair this plenary session and the speakers will each chair the work group for their respective topic. Rapporteurs: - Patrick Bolger Tom Brydges Darrell Piekarz

Friday May, 29

9:00 - 10:30 a.m.	Reports on work groups, Series B, by rapporteurs in plenary session.
11:00 - 12:30 p.m.	Plenary session to discuss final topic and make recommendations: indicators to be considered in future monitoring programs. Darrell Piekarz will chair the final session.
12:30 p.m.	Close - Plenary
2:00 - 5:00 p.m.	Rapporteurs and coordinators put together draft document.

APPENDIX C

Material handed out at the 27-29 May, 1987 Workshop

SUGGESTED QUESTIONS TO BE ADDRESSED BY WORK GROUPS

SERIES A

Each of the three work groups was asked to develop criteria for the selection of indicators at the level of organization that it was considering. A starting point might be to examine the criteria suggested by Ryder and Edwards (see attached Suitable Type I Organisms). The group was asked to keep in mind that in the selection of any indicator, the formulation of the environmental objective (ie. resources management goals, maintenance of ecosystem quality, protection of human health) is necessary.

Work Group A.1, Peter Hodson, Chair; Kristin Day, Rapporteur

Indicators at the Species Level

a. Evaluate characteristics of indicator species of Ryder and Edwards for the Great Lakes Basin.

b. Under what conditions are these types of species useful/not useful?

c. Identify indicator species for other ecological systems.

d. Identify criteria for indicator species with regard to the loading of toxic material to the environment.

Work Group A.2, David Bernard, Chair; Gail Krantzberg, Rapporteur

Indicators at the Community and System Level

a. What types of indicators/environments/thresholds are the most useful for assessing and managing the cumulative effects of many kinds of stesses?

b. Determine indicators of damage to homostatic mechanisms?

c. Examine Holling's concept of a "flip to a new domain of stability".

d. Build a case for new monitoring activities at the community and system level by government agencies.

Work Group A.3, Dan Pennock, Chair; Magda Havas, Rapporteur

Chemical Monitoring

a. Can increasing leakages of nutrients from ecosystems be used as an indication of upcoming ecosystem dysfunction? ie. Ca, Mg, K, N, P, etc.

b. Can accumulations of chemicals within ecosystems be monitored and related to potential dysfunctions?

c. Can fluxes of essential elements and/or potentially toxic elements be used as early warnings of problems?

d. How useful are studies of elemental speciation and changes in this, as indicators of ecosystem change?

e. Are the interfaces between air soil, air water, water sediment, air foliage etc. the key places to look for potential problems?

f. Are general measures of microbial activity useful in monitoring chemical accumulations?

SERIES B

To All Groups

To achieve sustainable management of "renewable natural resources", what are the most important variables which should be monitored by government?

Work Group B.1, Forestry, Hamish Kimmins, Chair; Tom Brydges, Rapporteur

Identify terrestrial species whose welfare reflects their state of their habitat and thus have implications for the management of forests, establishments of reserves and parks.

Work Group B.2, Fisheries, Henry Regier, Chair; Patrick Bolger, Rapporteur

In multiple-stressed systems, are there indicators of critical thresholds which may be used to alert managers?

Work Group B.3, Agriculture, Ted Huffman, Chair; Darrell Piekarz, Rapporteur

Identify indicators of resilience of soil ecosystems.

Suitable Type I Organisms:

a) will have potentially wide distribution within the Great Lakes Basin; (ie. will be a spatial indicator); this criterion may be determined on the basis of historic distribution for some organisms; or, if sedentary, occur in a well-mixed zone that allows exposure to large volumes of water over time; (ie. will be a temporal indicator); or, if vagile, move extensively throughout large parts of the system over time; (ie. will be an indicator in both time and space).

b) will reflect at least a moderate level of system integration; (ie. will interact directly with many other natural and human system components.

c) will be indigenous and a structurally stable component of the ecosystem and therefore will reflect adaptation to relatively unperturbed environmental conditions.

d) will have niche characteristics (an organismal attribute) and habitat requirements that are reasonably well understood and supported through documentation resulting from appropriate scientific studies.

e) will thrive in water of high quality and consequently be sensitive to a variety of human interventions within the ecosystem (or the converse of this) or will exhibit a graded response to a range of increasing levels of each human intervention.

f) will serve as a connective link between general measures of ecosystem quality and yet possess potential diagnostic capabilities for the determination of certain specific causes of ecosystem degradation (ie. PCB's bioconcentrated in flesh samples will be indicative of concentrations in the water column once the appropriate scale-factor has been applied).

g) will bear an orthogonal relationship to other ecosystem quality indicators; (ie. different indicators will reflect divergent manifestations of human impact and dimensional overlap will minimized insofar as possible.

h) may be typified by one or more historic data series or capable of retrospective monitoring. These data weries will show quantifiable evidence of past relative abundance of an indicator species during periods of relatively little human strress, or alternatively, provide quanlitative anecdotal information by creditable observers.

i) may be easily collected and measured for the purpose of quantifying standing stocks, in terms of numbers and biomass, using standard methods.

j) will consist of a temporal continuum of reproducing stocks.

k) are suitable subjects for laboratory experiments, expecially those designed to investigate cause and effect relationships.

l) respond to stresses in a way that will be readily identifiable and preferably, quantifiale.

m) will be important in their own right to humans (ie. may have inherent commercial, recreational or aesthetic value) and be readily recognized by the public; or, alternatively, may interact negatively with valued food organisms through predation or ompetition and thereby detract from their potential economic worth; or, may be a vital food source for a valued organism.

Editor's Note: see Ryder, R.A. and C.J. Edwards. 1985. eds., A Conceptual Approach for the Application of Biological Indicators of Ecosystem Quality in the Great Lakes Basin. International Joint Commission and the Great Lakes Fisheries Commission.

This report suggests candidate organisms as indicators for aquatic ecosystems.

owing are the criteria to be used for evaluating indicators of marine and Great Lake environental quality:

1. Can be applied nationally or over broad biophysical regions.	1) Consistent with NMPPO's mission: 2) within the scope of the proposed document on the status of marine environment; and 3) necessary to make nationiowide comparisons and identify regional and national trends.
2. Locically related to pollution caused by human acitivty in Great Lakes, U.S. estaurines, and coastal waters within U.S. jurisdiction.	Consistent with NMPPO's mission; indicators to be used to assess health of U.S. marine/estuarine and Great Lakes ecosystems.
3. Scientifically defensible.	Needed to ensure acceptance by scientific community and appropriate application of the indicator.
4. Adequate historical record and projected availability of ongoing/future data sets.	Needed to: 1) identify long-term trends, and 2) determine whether an indicator serves as an integrator of accumulated pollutant inputs or reflects short-term response to pulses in the environment.
5. Reliability and consistency of types of measurements used to assess indicator.	To ensure that comparisons of temporal and spatial trends are credible.
6. Simplicity (of measurement and interpretation).	1) Less controversy among scientific community; 2) minimize cost/effort of monitoring programs.
7. Data generally should be quantitative.	Needed to evaluate long-term trends as graphical representation.

APPENDIX D

Ecological Indicators and Indices Concerning Freshwater Ecosystems
References to work by H.A. Regier and colleagues

Ecological Indicators and Indices Concerning Freshwater Ecosystems

References to work by H.A. Regier and colleagues

A. Balanced information services for management.

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B. Indices in general.

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C. Indices of Properties of Fish Habitat, at Macroscale

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D. Indices of Fish Population Abundances ie. CUE

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E. Indices of properties of fish associations

1. Steedman, R.J., 1987. Degradative and rehabilitative transformations of stream fish associations under agricultural and urban land use in Southern Ontario. Submitted to Can. J. Fish. Aquat. Sci.

F. Indicators of ecosystem properties

- Salmonids as integrative indicators of ecosystem health.

1. Regier, H.A. 1980. Epilogue: Understanding of charr and a need for a "charr watch" pp. 889-893. In: Charr Monograph. E.K. Balon (ed.), Junk Publ., The Hague.
2. Regier, H.A. and G. Power, 1981. A wild tout and charr watch, pp. 77-83. In: Proc. Wild Trout Symp. II. Trout Unlimited, Washington.

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